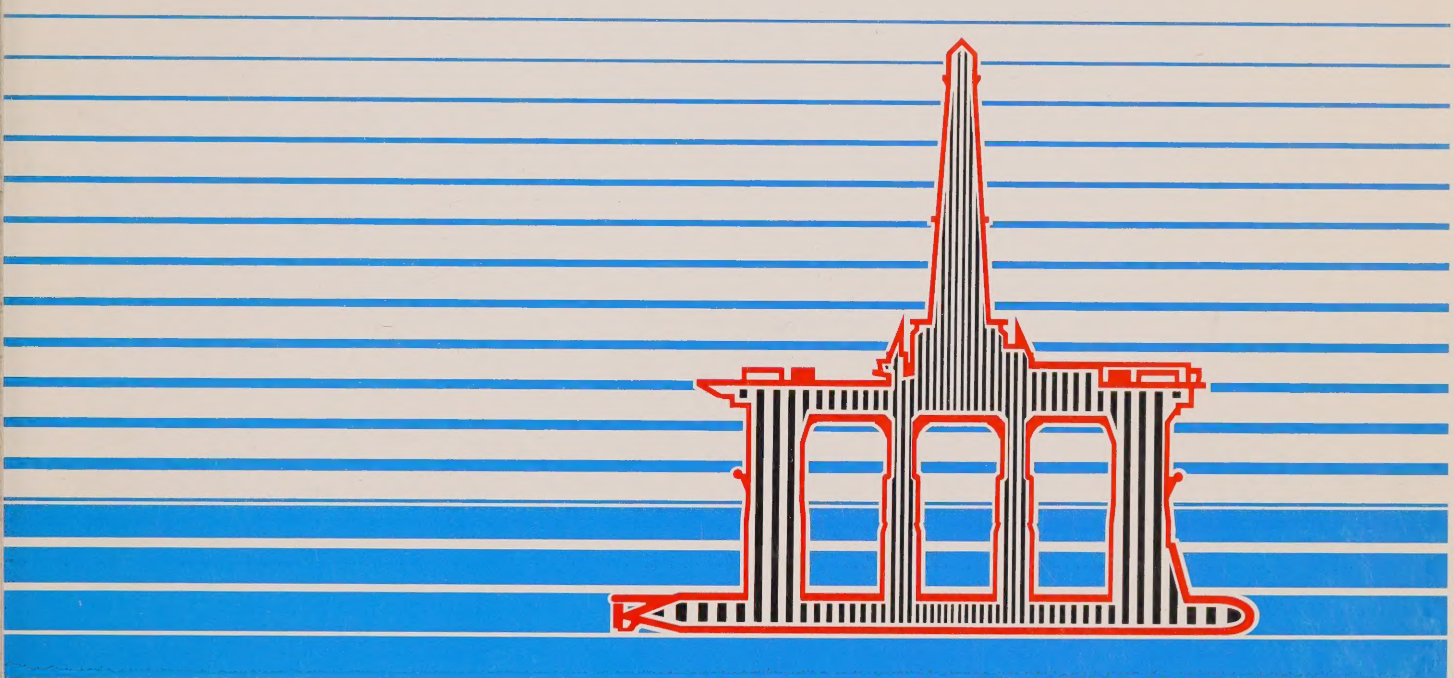
Royal Commission on the
Ocean Ranger Marine Disaster

Canada

Commission Royale sur le
Désastre Marin de l'*Ocean Ranger*

Newfoundland & Labrador



Report Two: Safety Offshore Eastern Canada

Summary of Studies & Seminars

15

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Report Two: Safety Offshore Eastern Canada
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The two reports of the Royal Commission on the *Ocean Ranger* Marine Disaster consist of the following four volumes:

Volume 1	**Report One: The Loss of the Semisubmersible Drill Rig *Ocean Ranger* and its Crew**
Volume 2	**Report Two: Safety Offshore Eastern Canada**
Volume 3	**Report Two: Safety Offshore Eastern Canada** ***Summary of Studies & Seminars***
Volume 4	**Report Two: Safety Offshore Eastern Canada** ***Conference Proceedings, 1984***

TABLE OF CONTENTS

PREFACE

During its inquiry into the safety of drilling operations off eastern Canada, the Royal Commission followed a consultative process. Factual information, views, and suggestions directed towards identifying practical means of improving safety were solicited. A study program was carried out for the Commission by consultants and study teams to provide a concise but comprehensive review of the state-of-the-art in the main areas of concern. Twenty-four studies were undertaken over a two-year period in four principal areas: environment, design, safety and training, and regulations. The draft study reports were reviewed by knowledgeable individuals from government, industry, and universities as well as by Commission staff, but the views expressed and the conclusions reached in these reports are those of the study authors. They represent input to rather than the output of the Royal Commission.

A number of seminars were also held to focus expert knowledge and opinion in several key fields and to update studies and fill gaps in the data base. The technical data gathered in the Part One inquiry, the reports prepared on the Part Two studies, briefs and submissions received, and the proceedings of seminars and the Conference on Safety Offshore Eastern Canada (see Volume IV) all form an important part of the data base for the final report.

Summaries of the seminar proceedings and of selected study reports are included in this volume. They have been prepared by Commission staff and contain the essential data from those documents. A complete set of seminar proceedings and reports has been deposited by the Royal Commission in the archives of the governments of Canada and Newfoundland, with the Canada Institute of Scientific and Technical Information (CISTI) at the National Research Council of Canada, and with the Centre for Newfoundland Studies at Memorial University of Newfoundland.

1

INTRODUCTION

INTRODUCTION

THE RISKS OF OFFSHORE DRILLING

The Risks of Offshore Oil and Gas Exploratory Drilling in Eastern Canadian Waters
Ian Burton, Director
Institute for Environmental Studies
University of Toronto
Toronto, Ontario
May 1984

A questioning attitude toward acceptable levels of risk is a characteristic of the last decades of the twentieth century. The explanation for that attitude is difficult to establish, in that, for Canadians at least, life today is safer than it has ever been. Our infant mortality rate is the among the lowest in the world and Canadian citizens live longer lives than people in most other countries. As the nation has prospered and developed, the wealth we have created has enabled us to reduce risks. Given this situation, how can the paradoxical and sometimes even obsessive preoccupation with risk be explained?

One major factor is that the type of risks we face has changed. The development of science and the application of technology have indeed created new risks that did not exist before. In general the new risks have so far proved to be less serious than the old risks that we have managed to control and reduce. On balance, development reduces risks.

While it is true that Canadians are more fearful about risks than ever before, it is not always the case that those most at risk are the most concerned. The concern for the dangers of offshore oil and gas exploration is a case in point. The concern for the safety of the workers and perhaps especially for the possibility of environmental damage sometimes seems to be greater the farther one gets away from the sea. In some ways this is an encouraging sign of national maturity; no civilization in the latter part of this century would wish to be seen as subjecting some of its citizens to an undue risk so that others may benefit. There is an overriding need for the question of risk in offshore oil and gas exploration to be approached in an open-minded, reasonable, and objective fashion.

A number of new methods of analysis have been developed precisely for the purpose of handling these difficult and often emotional considerations. Collectively called "risk assessment", these methods establish a framework to provide perspective and to facilitate choices; ultimately the choices to be made require judgement based on sound knowledge, sympathetic understanding, wisdom, and common sense. It should be noted that risk assessment is not a panacea. It provides a formula for decisions on the basis of quantitative analysis but does not thereby solve the problem of risk.

To develop an understanding of risk, it is necessary to realize that there is no such thing as "absolute safety". Risk is a part of life and the only successful method of dealing with it is to identify, assess, and choose your risks wisely. Excessive concern over the wrong risks does not lead to greater safety; it actually increases overall risk by leading to the neglect and exacerbation of other risks. A recent

example illustrates this point. When artificial sweeteners used in soft drinks, cyclamates, were withdrawn from the market because they were suspected of being carcinogenic, risk assessors pointed out that, were consumers of soft drinks to substitute an equivalent amount of sugar in their diet, there would be a resultant increase in obesity and heart disease. Calculations were made to show that the net effect on human health would be worse from consuming sugar than cyclamates. Thus the initial attempt to reduce risk could turn out to have quite the reverse effect.

In theory a balanced risk or minimum aggregate risk approach is desirable, but reliable comparisons of this kind are rarely possible. The lesson to be noted is that the apparent elimination of risk is not necessarily the safest course. Not to take the risks, of offshore oil and gas development, could well prove to be the more risky course. But to take these risks in a careless fashion, putting those involved at too high a risk would also be, if done knowingly, an irresponsible act.

■ *DEFINITION* Risk in everyday language means "exposure to possible loss or injury". Scientists have, however, developed a more technical definition of risk; namely, the probability of an event multiplied by its consequence or, where many events are being considered, the sum of the probabilities of those events times their consequences. Using this definition, risk has four components: the probability of an event occurring; the time span or conditions under which it can occur; its consequences; and the decision by some person or group to take the risk.

In theory, avoiding hazards is a way of eliminating the risk completely. Where chance, necessity, or the search for economic gain brings human activity into contact with hazards some risk exists. Safety is but the corollary of risk. In practical terms, the focus on safety is somewhat different from the focus on risk. It is almost axiomatic among safety experts that things are not safe enough and that safety should be improved. The risk analyst on the other hand must first determine the actual level of risk and then determine the level of risk that is acceptable.

Risk assessment may be thought of as the process of identifying, estimating, and evaluating risk in an economical, social, and political context. Risk identification and estimation can be approached in a scientific manner and to some extent may be expressed quantitatively. Risk evaluation is the social process undertaken to determine the terms and conditions under which a risk-generating activity should proceed.

■ *ANALYSIS* There are three approaches to the analysis of risk: historical analysis, the transfer of experience from similar circumstances, and risk modelling. The use of historical data has two major deficiencies: in many cases the necessary data to make reliable risk estimates is lacking, and the past record may not be a reliable guide to the future. Generally, experience and advances in technology steadily improve the safety record. At the same time, the larger scale of operations made possible by new technology increases the possibility of larger scale catastrophies.

In applying risk analysis to eastern Canada offshore oil exploration, there is a fundamental limitation to the historical approach; the record is too short to provide a reliable sample from which to estimate risk, especially for those events that occur with low frequency. In these circumstances one can transfer the experience gained elsewhere and apply it to the new location. A major question arises as to whether it is reasonable to suppose that the risks of offshore oil and gas exploration off Canada's East Coast are equivalent to those associated with similar activities in the North Sea or elsewhere in the world. There is no question that Canada, coming late to offshore exploration, benefits from the experience of others but Canadian offshore waters are different from those found in other parts of the world, with environmental conditions which may exceed those of other areas. These considerations imply that the data and the estimates used to transfer

experience from elsewhere must be treated with caution and some allowances must be made to account for the dissimilarities.

The recognized deficiencies of both the historical approach and the transfer of experience have led to the development of relatively new methods, all of which are variations of theoretical model building. This approach to risk analysis was first fully developed under the U.S. National Aeronautics and Space Administration (NASA). Space flight presented a situation where historical comparisons were non-existent and the transfer of experience from similar programs, such as that of the USSR, was impossible. These deficiencies resulted in the adaptation of a modelling approach.

Two modes of analysis are applied; fault-tree and event-tree analysis. In fault-tree analysis a specific fault is postulated. Then the possible causes of such a fault are determined and in this way a branching fault-tree is constructed working upstream away from the fault. Fault-trees may be used to estimate probabilities of failure by attaching probabilities to each step in the causal chain. In event-tree analysis an initiating event is postulated and the model is developed in a downstream direction by asking what the possible consequences of an initiating event could be. Again a branching network is developed, working away from the initial event.

The human imagination is an important limiting factor in both types of analysis. An accident sequence has to be thought of before it can be modelled and estimated. In a complex and large scale engineering system things can go wrong in so many different ways that it is not always possible to imagine them all in advance.

■ *ASSESSMENT AND EVALUATION* In the application of risk assessment to offshore exploratory drilling, historical analysis, transfer of experience, and risk modelling are not mutually exclusive. Risk modelling is substantially more expensive and time consuming than the other two. Because of the cost, the limitations of this method, and the relatively small scale of the Canadian offshore industry to date, it seems more sensible to use the simpler and less costly methods first and then decide what further analysis is needed and justified.

Once actual levels of risk have been measured, there remains the crucial task of evaluation which involves many decision makers at different levels. Federal and provincial governments, petroleum operators, MODU owners, contractors, workers, and their immediate families, all play some part in this evaluation. Members of each group have their own perception of risk which varies with the position they occupy and the responsibilities they are expected to bear. There is a tendency among scientific risk analysts to assume that measured risk is "real" whereas the perception of risk adopted by others, such as those at risk or the lay public at large, is somehow unreal or distorted. In fact, both points of view are risk perceptions. Even objective scientific methods apply value judgements, often in a concealed way. Both perspectives are valid perceptions of risk and both have to be taken under consideration by decision makers.

Similar comments may be made regarding the amount or level of risk that is "acceptable". A critical question then becomes "acceptable to whom?" Social conflicts arise in which a few are asked to bear a higher level of risk for the benefit of a large number. Resolution of these conflicts can be achieved if it is understood that adequate compensation has been paid to those who face higher risks for the general good and if it is understood that such risks are not accepted for all time but are only "tolerated". The fact that workers accept employment on offshore drilling units at a given compensation level does not mean that further efforts to reduce risk are not in order.

A common approach to risk evaluation is to compare one set of risks with another. Four comparisons are often made; with natural or background risk, with

the risk of alternatives, with other unrelated risks, and with benefits. In offshore drilling, a comparison with natural or background risk levels is not possible as there is no useful preexisting level of risk with which a comparison of incremental risk might be established. The second method, that of comparison with the risks of alternative methods, would involve the comparison of the risks of offshore drilling with onshore oil and gas exploration or with other energy-producing activities such as coal mining. The third type of risk comparison examines risks in one activity in relation to other activities that are not alternatives but are totally unrelated. A favourite comparison is with cigarette smoking; if smoking can be shown to be more hazardous than the risk-taking activity under consideration, the implication is that if people are prepared to accept the risks of smoking, then logically they have no reason to object to activities which produce much lower risks. Neither comparisons with alternatives nor those with non-related risks provide an adequate basis for accepting risk. They are, in fact, forms of risk rationalization. The fourth method, that of comparing risks with benefits, is a more valid criterion for risk evaluation.

There are three elements in the comparison: costs, benefits, and risks. For a given project or activity the preferred alternative may be specified as that which maximizes net benefits, at least risk and cost. After evaluating the risk in a particular activity, the degree to which safety can be increased by a further expenditure of funds must be assessed. If the cost of making a system "safe enough" is so high that it absorbs all or most of the profitability or benefit from the system, then it is probably too risky. Tolerable levels of risk and acceptable levels of profit or benefit are not fixed quantities and both may change according to circumstance. While in theory an objective of maximizing benefits over risks may be ideal, in practice some rule-of-thumb judgements have to be made. To make these difficult value judgements, it becomes essential to know existing accident and fatality rates and to be in a position to assess their causes. Calculations of accident rates based on a short period of record are statistically dubious; a first priority for the making of rational decisions concerning further expenditures on risk reduction is an adequate data base from which to specify the actual level of risk involved.

Broadly speaking, there are two directions in which risks may be reduced, both of which fall under the decision-making process that may be called risk management. In the first case, better systems design and operation can reduce the probability of accidents. In the second case, since accidents cannot be altogether eliminated, efforts can be made to mitigate the consequences. The mitigation of consequences is a generally neglected area of risk management.

■ *OFFSHORE DRILLING OPERATIONS* An assessment of risk in offshore drilling is hampered by a number of limitations. The brief history of offshore drilling makes analysis on an historical basis difficult and often impossible. The total service of MODUs worldwide is approximately 5,000 rig-years and in the eastern Canadian offshore less than 50 rig-years up to the end of 1983. This is far too short a period of record for the reliable estimation of the frequency of accidents, especially of the more rare events, because the data that do exist for this short period are neither complete nor reliable.

The available Canadian data collected by provincial governments are incomplete, lacking satisfactory reporting of person-hours worked. Therefore, calculations of accident rates and measures of safety performances are not possible. Federal government data are also incomplete because they are stored in a "raw" form and have not been abstracted or tabulated. In the United States, United Kingdom, and Norway similar data problems and analysis limitations exist. In making comparisons between operations in various nations, the difficulties of data deficiencies are compounded by a lack of standard reporting categories. Under present circumstances, data are incomplete and unreliable for each country and

are not strictly comparable internationally. Judgements, therefore, have to be made about which estimates or data sources are more reliable. In general, the higher figure has been used on the grounds that accidents and fatalities might go unreported but accidents and fatalities that have not occurred are unlikely to be invented. It is also thought more prudent to overestimate risk than to underestimate it. The purpose is not to exaggerate the risk but to be especially careful to avoid underestimating it.

The knowledge of causes is an important step in risk analysis. If certain causes occur more frequently than others, they represent the priority point of attack for risk management. In offshore oil exploration the cause of an accident can include weather and other environmental conditions, design and operation of the MODU itself, and capability of those on board to deal effectively with a dangerous situation. An examination of reports of accidents at sea reveals that in almost every case all three sets of factors are involved.

It is always a simplification to speak of a single cause or of a cause as a single event. In theory, the logical approach to the analysis of hazard events is to identify "event sequences". Risks can then be calculated in terms of the probability of whole event sequences rather than separate events. In the absence of that analysis, the analyst is forced to rely upon more primitive concepts of cause in order to relate them to the historical accident record. There are severe weaknesses in these classifications of cause from a statistical point of view. The categories are not mutually exclusive. Accidents may occur not only on the rig itself but also in associated activities such as diving.

Det norske Veritas has recently established a worldwide offshore accident data bank which indicates that the number of fatalities per 1,000 persons working offshore has declined over the period 1970 to 1978. This decline is interrupted by the sequence of three major accidents in the 1979 to 1982 period resulting in the loss of 277 lives. In fact, of the 486 lives lost worldwide in the period 1970 to 1982, a total of 349 or 72 percent were lost in four major disasters. It would seem reasonable for the purposes of risk analysis to divide offshore drilling fatalities and injuries into two distinct populations. These might be described as marine disasters and industrial accidents. In the case of marine disasters the focus has to be on making MODUs less vulnerable to accidents that may result in their total loss, and on developing emergency plans and precautions to maximize the possibility of rescue when a disaster does occur. In the case of industrial accidents it may be that the safety precautions applied on land with some necessary changes are sufficient.

The most comprehensive study of the safety of offshore oil exploration and production activities so far conducted in North America is a U.S. National Research Council study entitled *Safety and Offshore Oil – Report of the Committee of Assessment of Safety of Offshore Continental Shelf Activities* (1981). That study noted the deficiencies in existing data and lamented the fact that no comprehensive source of data on accidents on the U.S. outer continental shelf existed. This resulted in workplace safety data that were neither consistent nor comparable in a national or international sense. The study concluded that a standard accident reporting form, collected by a single agency, could provide the kind of information needed to gain a better understanding of the causal factors and characteristics of workers that could lead to improved safety.

The report stated that at the end of 1979 about 61,500 U.S. workers were regularly employed in offshore continental shelf oil and gas exploration, development, and production. The estimate was qualified as very tentative since no census had ever been undertaken. During the period 1970 to 1978 the U.S. Geological Survey reported that 187 workers were killed in 116 accidents. Between 1962 and 1977 there was a fourfold increase in the number of person-hours worked, but

a 35 percent decrease in accident frequency. In comparing the risks of work offshore to that of other industries, the report found that the frequency of injuries in oil and gas operations was comparable to that in industries such as mining, marine transportation, and heavy construction and that the injury and illness rates per 100 full-time workers was about the same as that found in general manufacturing. Comparisons of this sort must be qualified by the knowledge that definitions of "injury" and reporting practices vary widely from industry to industry and company to company. In a comparison of fatality rates between the Gulf of Mexico and the North Sea it was concluded that incidents of fatalities were lower in the Gulf of Mexico and holding relatively constant. The study also indicated that incidents of fatalities were declining in the North Sea.

The study went on to ascribe a substantial part of the responsibility for workplace accidents to worker characteristics, limitations, and attitudes. Experience was noted as a key factor, in that 76.5 percent of injuries occurred to employees with less than one year on the job and 54.8 percent of all injuries occurred within the first six months of employment. The study concluded that a principal item demanding attention in improving workplace safety was not technology but improvement in personnel performance.

A major review of the safety in the United Kingdom sector of the North Sea was conducted in 1980 and presented in the report *Offshore Safety* commonly referred to as the "Burgoyne Report". As in all other credible reports on this subject the Burgoyne Report contains the inevitable lament about the availability and the quality of data. Doubts were cast on the validity of figures for minor accidents because of underreporting. Similarly, the figures for dangerous occurrences were thought to be unreliable because of the doubt about the definition of a reportable occurrence and the difficulty of educating all concerned to make such reports.

According to the U.K. Department of Energy estimates, the work force in the United Kingdom sector of the North Sea grew from a total of 4,030 in 1974 to approximately 12,500 by 1978. The fatality rate per 1,000 employed ranged from 0.8 to 2.0. This compares with 0.6 to 1.12 per 1,000 "workers per year" in the United States and 1.7 to 2.8 fatalities per "1000 man-years" in the Norwegian sector of the North Sea. It is not certain that the estimates are comparable since the "per 1000 employed" used in the U.K. study and "per 1000 workers per year" in the U.S. study are not necessarily the same as "per 1000 man-years" for Norway.

The Burgoyne Report concluded that an offshore worker is about twice as likely to have an accident as a worker in general manufacturing and about half as likely as a miner. It was concluded, however, that an accident offshore is much more likely to be fatal.

More detailed and comprehensive studies of risk have been carried out for the Norwegian offshore petroleum industry than for any other in the world. Norwegian studies have taken as their point of departure the need to estimate risk levels before judgements are made about safety levels and procedures. Nevertheless, the problems with data encountered elsewhere are also found in the 1979 report of the Royal Norwegian Council for Scientific and Industrial Research, *Risk Assessment, A Study of Risk Levels Within Norwegian Offshore Petroleum Activities*. Variations in definition, coverage, and method of collection resulted in wide divergencies among data sources.

The upper estimates of the size of the Norwegian Continental Shelf work force grew from 100 person-years in 1966 to 16,705 person-years in 1978. The high estimate of person-years worked tripled between 1975 and 1978. There were 82 fatalities (Norwegians and foreigners) reported in different offshore activities from 1966 up to and including 1978. The largest single area of fatalities was in the category of field development involving helicopters. The data analysis revealed

that 42 percent of the 82 fatalities were caused by helicopter crashes and ditching; 21 percent were caused by what could be called industrial accidents; 11 percent occurred during emergency evacuation (including the grounding of the *Deep Sea Driller*); 10 percent were diving accidents; 4 percent occurred during drilling operations; and 12 percent were allocated to the miscellaneous category. The Norwegian offshore industry had a fatality rate for that period in the range of 1.7 to 2.8 fatalities per 1,000 person-years. If helicopter accidents and the *Deep Sea Driller* grounding are excluded the rate drops to the range of 0.85 to 1.4 fatalities per 1,000 person-years.

The report noted that the injury frequency on fixed and mobile platforms offshore was comparable to that in land-based activities such as mining and wood conversion. Injury seemed to be more frequent on MODUs than on fixed installations (production platforms) and this was attributed to the drilling activity. To reduce the accident frequency the report suggested that the drilling activity be studied more closely.

■ *THE EASTERN CANADA OFFSHORE AREA* In the presence of a short operating history offshore eastern Canada and the absence of reliable and complete data, numerous assumptions have had to be made in order to establish an estimate of the total number of rig-years of operation and the size of the work force. These estimates provide a reasonable basis for some comparisons. In comparing the frequency of disabling injuries in oil exploration off Nova Scotia with the rate for Norway, both rates fall within the same order of magnitude, within the limits estimated for person-hours worked. It is not known, however, if the reporting requirements for "injuries" in Norwegian data correspond to those for disabling injuries in Nova Scotia. The most that can be said is that the rates appear similar; no radically different rates have been detected. The average frequency rates for lost-time accidents or disabling injuries off Newfoundland are of the same order of magnitude as seen in Nova Scotia and Norway.

Nevertheless, serious doubt is cast on the value of average frequency data when the range is large. For example, one semisubmersible operating offshore Newfoundland in 1980 reported an average of 56.48 accidents per month, but the monthly values ranged from zero accidents in each of seven months to 217.7 accidents in a single month. It is conceivable that such extreme variations might be caused by radical changes in conditions, such as severe deck icing, but incomplete reporting is the more likely explanation. For instance, the Newfoundland and Labrador Petroleum Directorate information for 1980 shows data from only three rigs, whereas other data sources report that there were eight rigs operating off Newfoundland in 1980. The frequency of lost time accidents in Newfoundland and Labrador areas for the period 1978 to 1983 is generally lower than that reported for Norway in the same period, but again, the lack of accuracy in the data and doubts regarding their strict comparability permit no more than the conclusion that they are not radically different.

■ *CONCLUSIONS* If accident and fatality rates are considered to be important in Canada as a means of assessing risks, monitoring safety performance, and providing comparable data, then a single accident reporting form collected by a single agency with the authority to ensure that its reports are complete and accurate is necessary. In addition, standardization of reporting categories and definitions is desirable in both the national and international forum.

The risk of fatality for an offshore oil rig worker in eastern Canada on an annual basis lies somewhere between 0.006 and 0.0004. While this is not a very precise estimate, it is the most that can be said on the basis of present data. The available data on injury rates in the four countries studied do not even allow for such an imprecise estimate, although this analysis has not been able to establish any major differences in injury rates among the four countries.

On the basis of the limited comparison of Canadian offshore exploration with land-based industries, it might be judged that offshore drilling and related activities are safer in terms of industrial accident rates, and more dangerous only in terms of the low probability of a ''marine disaster''. It is quite clear that the limited periods of record make risk analysis, based on the type of offshore activity, impractical. It is an axiom of risk analysis that accidental events can be reduced in frequency but not completely eliminated; risk management must include the making of preparations to help reduce the effects of accidents when they do occur.

Summary of Risk Analysis Seminar

On May 2, 1984, the Royal Commission sponsored a one-day seminar to investigate the application of analytical techniques for the identification and assessment of risk in offshore drilling. The participants were invited from offshore industry and regulatory groups and also from the nuclear industry, where risk analysis techniques have been employed for many years as part of the management decision-making process.

Risk analysis involves methods of estimating the probability and consequence of adverse events; such a process is not designed to "predict" future events, but to provide a rational basis for decisions aimed at minimizing the occurrence or consequences of such events. Risk analysis also provides a framework for processing large amounts of data to facilitate review and assessment.

It was noted by the participants that risk analysis has a number of limitations. There is considerable difficulty in estimating the possibility and consequences of low probability events, and such estimates are often the subject of disagreement. In addition, risk analysis techniques involve subjective input, especially where objective data are questionable or non-existent, and the opinions and judgement of the analyst are reflected in the results. Risk analysts must also be aware that changes in technology and significant corrective action instigated to compensate for past accidents may limit the effectiveness of comparison with historical data.

The Canadian and American nuclear industries have benefited from the application of risk analysis techniques for almost 20 years. During the last 10 years, these techniques have evolved as a major element of the industrial and regulatory decision-making process in a number of industries, including the oil and gas production industry. The process has been improved by developments in data processing techniques and computer simulation, especially where large volumes of data are involved. The general perception of the participants was that the benefits of risk analysis outweigh the limitations imposed by the necessity of qualitative input.

To date, in the offshore oil industry, only the Norwegian Petroleum Directorate (NPD) has introduced a regulatory requirement for the application of such techniques. To acknowledge the alternative ways of performing these evaluations and to encourage operators to develop suitable techniques for offshore application, the requirement has been introduced in the form of a guideline, as opposed to a regulation. One representative of NPD pointed out that, although the industry was initially somewhat reticent about having a regulatory requirement for risk analysis, every operator now performs a broader analysis than required by the NPD guideline. It was generally agreed that the regulatory framework for risk analysis should avoid the stipulation of arbitrary numbers for "acceptable" levels of risk, as this obscures the goal of the assessment and tends to turn it into an exercise of proving that the situation is "safe enough". The operator must be convinced that he is carrying out the assessment for his own benefit, to identify problems and implement effective improvements.

The use of risk analysis techniques for evaluating existing offshore installations and operations was considered a reasonable and beneficial proposition; the application of the same techniques used during the design of offshore systems may have an even greater effect on the level of safety achieved. The earlier that risk analysis is employed in the design process, the greater the potential for identifying and decreasing risk factors.

A considerable amount of discussion took place regarding the public perception of risk, and the regulators' responsibilities to the public, the offshore workers,

and the petroleum industry. It was noted that the mandate of the regulator should be to establish levels of risk that are "acceptable", possibly in comparison to the risks encountered by workers in other industries. Risk levels should also be established through the comparison of overall risk with potential benefits, and the regulator should opt to protect the interests of those who are not in a position to influence the decision-making process. Risk analysis was seen as an adjunct to more subjective influences, such as the public perception of and the potential benefits from offshore activities.

In general, it was agreed that the information obtained through the judicious and systematic application of risk analysis techniques considerably exceeds that which can be obtained from a less structured, intuitive inspection. Risk analysis is a powerful and desirable tool for identifying and evaluating risk levels and provides a basis for establishing methods of eliminating or mitigating the consequences of such risks.

2

ENVIRONMENT

ENVIRONMENT

ICE AND ICE MANAGEMENT

A Review of Ice Information for Offshore Eastern Canada
NORDCO Limited
St. John's, Newfoundland
August 1984

An Evaluation of Ice Management Systems in Support of Eastern Canada Offshore Exploratory Drilling Operations
Manadrill Drilling Management Inc.
Calgary, Alberta
August 1984

Three categories of ice are encountered in the study area: glacial ice in the form of icebergs, sea ice, and freezing precipitation or spray. The last of these creates super-structure icing, which while long recognized as a problem for fishing vessels, has only recently been addressed as a concern for offshore drilling operations. The other two forms of ice, however, have been major factors for a number of years in determining drilling schedules and the type of unit employed. Year-round drilling has only been possible off Nova Scotia and, with due attention to icebergs and occasional sea ice, on the Grand Banks. In both these locations anchored semi-submersibles are routinely used, although in the shallow waters close to Sable Island and in the Gulf of St. Lawrence, jack-up units are often preferred. Farther north off the Labrador Coast and in the Davis Strait, drilling is limited to the summer months and to dynamically-positioned drillships or semisubmersibles that are mobile enough to move away from ice on short notice. In the extreme north, off Lancaster Sound, drilling permits have been sought but actual drilling has not yet begun.

None of the drilling units used so far on the East Coast have been "ice class", although some of the semisubmersibles have extra strengthening in their vertical columns. Supply boats, particularly those used off Labrador, are often ice class, for example, Lloyd's Arctic Class 2 or 3, since these vessels are frequently required to tow icebergs or deflect small pieces of ice away from rigs.

The basic methods used in the industry for dealing with icebergs were developed in the early 1970s for operations on the Labrador Shelf. The ice management strategy is based on avoidance. The security of the drilling operation depends on the detection of all potentially hazardous ice or icebergs in sufficient time to either deflect the ice, or move the drilling vessel out of its path. The possibility of a collision between a drilling unit and an iceberg is thus limited to those situations when the ice is not detected in time to move the unit, or when deflection is not possible and the unit is for some reason unable to move off the site.

■ *ICEBERGS* Icebergs are defined in terms of their approximate mass. The smallest pieces, referred to as growlers, have dimensions of up to 1 metre of freeboard, 6 metres in length, and 200 tonnes in mass. A "bergy bit" has a sail height (height above sea level) of 1 to 5 metres, a length of 6 to 20 metres and a mass of 200 to 7,000 tonnes. Icebergs that exceed these approximate dimensions are simply referred to as small, medium, large, and very large icebergs with relative sizes established for each category.

The size and shape of an iceberg will directly affect its detectability, its

response to both environmental forces and deflection strategies, and the impact that it would have in collision with an offshore platform.

The method normally used to calculate the above-water dimensions of an iceberg is to measure angles with a sextant and ranges with radar or a visual range finder. Since there is a fixed relationship between the above- and below-water mass of icebergs, the mass can be estimated from this information by using standard formulae. In some cases aerial stereo photography has been used to estimate iceberg mass. Length and draft are also important iceberg dimensions. Draft is normally measured using a side scan sonar or estimated from the density of the ice and the iceberg's above-water geometry.

The principal source of data on iceberg dimensions off the East Coast are the observations made by oil companies in support of their offshore drilling programs. Data from drill sites indicate that growlers are frequently not observed even when they are closer than ten kilometres, and they are not always included in the statistics when they are observed.

The maximum credible size of an iceberg may not be an important factor in terms of drilling unit design or safety. The maximum credible iceberg has a very low probability of occurrence, an even lower probability of hitting a structure since it would be easy to detect and track, and practically no probability of colliding at any considerable speed. If the probability of impact is held constant, the maximum energy level involved in a collision is associated not with the maximum credible iceberg but with a much smaller iceberg travelling at higher speeds.

Each year tens of thousands of icebergs calve from the glaciers of West Greenland and, to a lesser extent, Baffin Island but only a fraction of them find their way out of the fjords and into Baffin Bay, and an even smaller number will survive the 3,000 kilometre two-year journey along the Baffin and Labrador Coasts. South of 49 degrees north latitude the icebergs follow two branches; the inshore branch flows southward through the Avalon Channel while the offshore branch follows the eastern edge of the Grand Banks. Once an iceberg is free of pack ice and drifting in open and warmer water it decays rapidly. A small berg in +2°C water will have disappeared in about nine days and in 10°C water in three days.

The number of icebergs moving through a cross section in a given time interval is known as the iceberg flux and in eastern Canadian waters variability is its principal characteristic. The maximum flux usually occurs in April and May on the Grand Banks, in May off Labrador, and in July in Baffin Bay; the minimum flux is in October, November, and December in all areas. The annual flux across 48 degrees north latitude, which has been documented by the International Ice Patrol since 1913, ranges from zero to as high as 1,500 icebergs per year, thus demonstrating how extreme the interannual variability can be.

There is also operational interest in information about the size distribution of bergs. This is well known for Labrador because of the large data set accumulated during the several years of drilling along that coast in the 1970s. The data base for the Grand Banks is not nearly as well developed. Analyses suggest that in the waters off Labrador about one-third of all icebergs have displacements of a million tonnes or more while on the Grand Banks only about ten percent are that large. The populations upon which these percentages are based do not include bergy bits and growlers of under 1,000 tonnes because of the lack of any reliable data on their numbers. They tend to be short-lived, difficult to detect under adverse conditions, and when detected are not always reported.

The movement of an iceberg is governed largely by wind and current. Since both wind and current vary considerably over time and distance, large variations in iceberg speed and direction occur even over distances as short as a few kilometres. Some conclusions can be drawn regarding iceberg drift speeds in off-

shore areas of eastern Canada. For sites not in the main current, iceberg drift speeds averaged over several days range from 0.10 to 0.25 metres per second (m/s) while in high current environments these can approach 0.50 m/s. A few observations of short duration drift speeds of 2.0 m/s and daily averages of 1.5 m/s have been made in high current environments under severe storm conditions. There is very little quantitative data and no field data on expected instantaneous speeds of small icebergs such as growlers in waves.

At present the only area for which design criteria for maximum iceberg drift speeds have been proposed is Hibernia. Both the Newfoundland and Labrador Petroleum Directorate and Mobil Oil Canada Ltd. proposed a maximum of 1.0 m/s. Although no design criteria have been proposed for Labrador, a value of 0.80 m/s is quoted in the Offshore Labrador Initial Environment Assessment as the maximum iceberg drift speed. Other research suggests that the Hibernia figure represents a long-term maximum, and that both values need to be reassessed.

A second aspect of iceberg drift which is important in designing impact probability models (and which several of the existing models do not take into account) is the direction of drift. Analyses of data collected at drill sites in the Labrador Sea have demonstrated that, although there is normally a predominant drift pattern, icebergs move in all directions.

The mechanical properties of ice define its strength, an important aspect in determining the effect this material will have on impact with a structure. Different types of loading (compression, bending, indentation, shearing, pulling) are used to identify different failure modes (cracking, crushing). Mechanical properties are difficult to quantify because of their variability with temperature, age of ice, brine content, and the manner of formation of the ice. This natural variability cannot be replicated in the laboratory and field measurements are difficult to obtain. Further, if ice is taken from its natural setting, many of the variables affecting its mechanical properties (temperature, brine drainage) change dramatically. For these reasons, there are few measurements of the mechanical properties of ice.

Iceberg ice is characterized by small bubbles entrapped during the formation of the glacier when pressure converts snow into ice. These small bubbles of compressed air are in the order of a few tenths of a millimetre in diameter and occur in the order of a few hundred per cubic centimetre. The limited test results which are available indicate that iceberg ice has exhibited a higher strength than, for example, lake ice; this characteristic is attributed to these bubbles which appear to inhibit crack propagation.

■ *SEA ICE* Sea ice is formed by the freezing of the sea surface; pack ice is free-floating sea ice. Once an ice sheet has formed, its visual appearance reflects its stage of development and hence a classification terminology has evolved for identification of young ice (newly formed, dark, thin) through to first-year ice (older, white, thick). Ice which survives the summer melt is subjected to brine drainage. As a result, this older ice (second or multiyear ice) is considerably stronger than first-year ice.

Pack ice occasionally extends to the Hibernia area during the winter months, and the ice edge is normally just north of the drill sites off Labrador at the start of the season. Throughout the northern part of the study area (Baffin Bay, Lancaster Sound) sea ice is present for most of the year and would pose problems to any drilling activities. Although pack ice from the Gulf of St. Lawrence does occasionally cover the northern Scotian Shelf, it has not been reported at Sable Island.

Data on sea ice types and concentrations in the study area are normally obtained from ship, shore, aerial, and satellite observations and are processed by the Ice Central Branch of the Atmospheric Environment Service (AES). This branch uses aircraft to provide sea ice information on the Grand Banks, Labrador Coast, and the Gulf of St. Lawrence. The service has been much improved

recently with the introduction of Side-Looking Airborne Radar (SLAR) on the aircraft. Because of the large geographical area involved and the mandate of AES to service shipping interests as well as the oil industry, coverage of the Hibernia area during the winter and of the Labrador Coast during the spring is limited to once every two to three days, but this may vary considerably. In both these areas the oil industry has developed its own ice reconnaissance programs which supplement the AES flights.

New sea ice begins to form in late September in northern Baffin Bay and slowly advances southward. By late December the Labrador Coast is completely enclosed by ice, and ice is starting to form in the Gulf of St. Lawrence. By mid-March the sea ice has reached its maximum extent covering most of the Gulf of St. Lawrence and much of the northern Grand Banks. This ice begins to melt in April and by May these two areas are usually clear. The Labrador Coast clears of ice during June and July, and by mid-August the southern extent of pack ice is restricted to Baffin Bay. Mid-September generally represents the minimum distribution of sea ice. Seasonal variations in the timing and extent of ice coverage can range up to about a month.

The rate of movement of the ice edge is the most important consideration for drilling near the pack ice edge since this factor determines the lead time available to move the drilling unit off the site. Analyses of pack ice drift speeds off Labrador suggest a maximum observed drift speed of 0.8 m/s with mean speeds ranging from 0.17 to 0.32 m/s. Most of the measurements available are from pack ice situations; isolated floes could be expected to travel considerably faster. There are few measurements of sea ice drift speeds on the Grand Banks; however, a maximum rate of advance of the ice edge towards the Hibernia site of 277 kilometres per week (average speed 0.43 m/s) has been noted. Rapid advances of the pack ice on the Grand Banks normally occur in the area of the Labrador current during periods of strong north or northwest winds behind a low pressure system. During one such instance the AES ice charts for March 1973 reported movement of sea ice south through the Avalon Channel at a rate in excess of 50 kilometres per day (0.6 m/s).

Although first-year sea ice rarely grows to more than two metres in thickness through the process of freezing, other conditions related to the pack ice environment can result in considerably thicker floes. Rafting, where one ice sheet overrides another, is a factor in the building up of thinner ice, while ridging, where a line of broken ice is forced up or down by contact between individual pieces under pressure, can occur in thick ice and result in the formation of even thicker floes as the ice blocks comprising the ridge become frozen together. This latter phenomenon is most likely to occur in areas with high concentrations of ice of varying degrees of thickness where there is considerable interaction between floes. Commonly, ridge formation occurs when currents squeeze the pack ice against land or landlocked ice. In addition, ridges are more likely to retain their identity if they are formed in a cold environment with little wave action. For these reasons ridge formation occurs more frequently in the northern parts of the study area than on the Grand Banks.

Ice thickness measurements in the Labrador Sea indicate that the mean first-year ice thickness during the winter months ranges from 0.5 to 3 metres, with the maximum thickness near 5 metres. There are few measurements of multiyear floes but the available data indicate that thicknesses in excess of 14 metres are possible. There are not enough representative observations from the Grand Banks to determine the mean or extreme sea ice thicknesses in this area.

The floe size distribution within the study area varies regionally, seasonally, and with the distance from the ice edge. The largest ice floes, found in Baffin Bay and off the Labrador Coast during the winter months, can reach tens of kilometres

in diameter and are composed of smaller floes that have frozen together. Since these floes would be quickly broken up by wave action, they are normally found well inside the ice edge. Near the edge of the Labrador pack in winter there is normally a zone 5 to 10 kilometres wide of small, broken floes with diameters of 10 to 20 metres. Measurements of floe size on the Grand Banks indicate that within 100 kilometres of the ice edge the majority of ice floes will be less than 30 metres in diameter. Again data limitations preclude estimates of maximum floe size for this area.

Sea ice is also measured in relation to ridges since this surface feature may affect ice/vessel interactions. Laser profilometer data collected off Labrador indicate that the largest ridge observed had a sail height of three metres. Using sail to keel ratios of 3:1 to 5:1, these measurements would give maximum ridge thicknesses of 12 to 18 metres. Based on the same statistics, a typical ridge in this area has a height of approximately 1.5 metres and a total thickness of from 6 to 9 metres. There are few measurements of ridge height on the Grand Banks.

There are limited measurements of the mechanical properties of sea ice; most are from the Labrador offshore, none have been reported from the Grand Banks. The strength of sea ice varies principally with temperature and brine volume. Old, multiyear ice can be expected to have higher failure strength than first-year ice.

■ *ICING* . Icing can originate either from freezing sea spray or flooding by waves, or from atmospheric sources such as freezing precipitation, rime icing in clouds, fog, and wet snow which freezes on contact with a surface. These icing events, particularly when they occur either simultaneously or sequentially, have a number of direct and indirect effects on drilling operations. The stability of drilling platforms and support vessels is reduced by ice loading; the operation of helicopters and fixed-wing aircraft is restricted by rime icing; the danger of on-deck accidents is increased by ice encrustment; and the operation of safety equipment such as lifeboats and rafts is interfered with by several of these conditions. Research attempting to establish maximum icing conditions and loads for supply boats and platforms is seriously hampered by the lack of reliable data on ice accretion on offshore structures.

Freezing spray, the most common source of icing, occurs when spray droplets are cooled below their freezing point without freezing. When these supercooled droplets come into contact with a cold surface, icing occurs. The ratio of ice accumulation from freezing spray is a function of the relative wind speed, sea state, the air and water temperature, and the physical features of the structure. A small vessel such as an offshore supply boat, steaming into the wind in the open sea will start to generate spray at wind speeds of 17 to 21 knots and will be showered in spray in winds of 22 to 27 knots. Spray blown from the tops of waves, the primary type of icing to affect a MODU, is not a major factor until winds reach 41 to 47 knots. At air temperatures of $-3°C$ ice accumulation from spray starts to be a problem and the rate of accumulation increases with lowering air temperatures. As sea surface temperatures rise from the freezing point, the formation of freezing spray tends to lessen but icing has been reported with water temperatures as high as 6°C.

Minimal observations of sea spray icing are included as part of the standard marine meteorological reports sent in by ships and drilling units off the East Coast of Canada. This data is greatly limited by lack of detail, by procedural variations, and by the frequent failure of ships to report on this factor. The National Research Council of Canada (NRC) attempted to collect a better data set from 1968 to 1979, but the study was limited in its spatial coverage and dependent on reports from fishing vessels. To supplement this limited data base, a number of empirical and theoretical prediction models have been developed to calculate the rate of sea

spray icing using various combinations of air temperature, wind speed, and sea surface temperature.

Sea spray icing is a problem in all regions of the study area. The most severe icing occurs in February except in areas with seasonal ice coverage where it occurs prior to freeze up. A study for Mobil Oil of sea spray icing on the Hibernia and Sable Island sites predicts the average frequency of severe icing during February as 8 percent at Sable Island and 9.5 to 12.5 percent at Hibernia. This study also determines some parameters for the most severe sea spray icing conditions at Hibernia, with the overall worst conditions being cold northwest winds behind a low-pressure system, particularly one stalled in the Labrador Sea for several days. This study arrived at a figure for maximum potential ice load from sea spray icing of 549 tonnes using a number of assumptions regarding the type of rig and the distribution of ice on it.

Atmospheric sources of ice accretion on offshore structures and service vehicles include freezing precipitation, supercooled fog (cloud icing), and wet snow which turns to ice. Snow which accumulates on deck surfaces but does not freeze is also within this category.

The sources of data on atmospheric icing in the study area are meteorological reports from transient ships, drilling platforms, and land stations. None of these sources is entirely reliable. While observations from transient ships provide the largest amount of information, they seldom provide a continuous record of an icing event. Drilling platforms provide continuous coverage but with little detail and few long-term records. Land station reports supply detail on icing conditions but rarely specific measurements. In all these cases, reports would be more helpful if they provided measurements of the amount of precipitation and the thickness of ice on standard surfaces. To overcome the problem of an inadequate data base, various methods have been developed to compute ice thickness using wind speed, air temperature, and precipitation observations.

Freezing precipitation is estimated to occur less than one percent of the time for all months at the Hibernia site but little data is available for other areas. Rime icing is caused by supercooled fog which freezes on contact with a surface. Due to its low water content this type of icing is generally not a problem for platforms or vessels, but can be a serious one for fast-moving objects like helicopters or aircraft. Forecasts of cloud or rime icing frequently prevent flights, or force pilots to change altitude or alter flight plans. This problem could become serious in an emergency situation where helicopters are unable to fly because of rime icing, or where an airborne craft is unable to change altitude because of mechanical problems.

When calculating ice loadings on vessels and drilling platforms the possibility of combinations of icing events occurring either simultaneously or sequentially must be considered. A Mobil Oil study of the Hibernia site concluded that a combination of sea spray with freezing precipitation and snow could result in the greatest accumulations of ice, that these events would be unlikely to occur together but they would frequently occur sequentially, and that they were relatively independent (that is a maximum sea spray event would be unlikely to be followed by a maximum precipitation event). A maximum ice load from all sources (marine and atmospheric) used the maximum sea spray event plus 50 percent of the maximum freezing precipitation event to produce a combined ice load of 831 tonnes. (Snow accumulation accounted for 17 percent of this amount.) Attempts to estimate icing loads, and particularly extreme or 100-year events are seriously limited by the lack of reliable data bases covering 20 years or more and by the fact that the bulk of data collection is done by ships which tend to avoid areas where severe icing is reported. For this reason the Mobil Oil study identified the most severe event rather than attempting to calculate the 100-year event.

The lack of reliable observations of icing on supply boats and particularly on semisubmersible drilling platforms presents difficulties for designers, operators, and regulatory agencies in estimating and controlling ice accumulation on offshore structures. Of particular importance are lack of understanding regarding icing on the underside of platforms, vertical profiles of icing rates, and effects of icing on the operation of safety equipment.

■ *ICE MANAGEMENT* Current East Coast drilling practice assumes all ice will be detected in sufficient time to take any action necessary to ensure the safety of the operation under any weather condition or drilling situation. To this end an ice management system has been put in place which, to date, has been successful. There have been no reports of serious damage by ice to either rigs or supply vessels. It is, however, well recognized that there is much room for improvement to ensure that this safety record is maintained.

Only from the Grand Banks northward does floating ice pose a significant concern to drilling operations. During the winters of 1982-83 and 1983-84, the Grand Banks experienced severe ice conditions for the first time since winter drilling commenced. Programs to manage the situation were quickly developed, building on the earlier drilling experience with pack ice and icebergs in Labrador. The underlying policy is to avoid contact with the ice. The programs consist primarily of a detailed ice surveillance system, a site-specific ice detection system, and a series of procedures for either deflecting the ice from the site by towing or propeller washing or moving the drilling unit off the well location.

The effectiveness of any ice management strategy depends on the technical ability to detect, monitor, and measure ice and ice movement in a systematic manner. There is an ice observer on duty at all times on each drilling unit. Overall detection performance has been conclusively linked to the technical training, practical experience, and constant vigilance of these observers. The primary ice detection tool on board is marine radar, supplemented with radar and visual observations from other resources, usually supply boats and aircraft. Once detected, the ice is monitored, at regular intervals, to evaluate the level of threat involved and to decide whether collision avoidance procedures are necessary. This decision depends on the distance of the ice from the unit; the size and draft of the iceberg (with respect to wellhead damage potential); the drift speed, direction, and trajectory of the ice; the safe stand-down time involved in moving the unit; and environmental constraints such as weather and sea state. The procedure for assigning level of threat is based on a configuration of concentric alert zones centred on the drilling vessel.

Ice management programs rely on information on both regional and local scales. Local data originate from the ice observers on an individual drilling unit; regional data are provided by a mixture of government and dedicated operator-sponsored agencies and sources of opportunity. In the case of a dynamically-positioned drilling unit, local control will normally be sufficient since the unit can withdraw fairly quickly. Moored drilling units take considerably longer to move off location, and the decision to suspend operations or to prepare for moving off may have to be made very shortly after a potentially troublesome iceberg or pack ice drifts within local surveillance range. Because the last line of defence for a MODU is its quick release mooring system, it is important that this system be reliable, simple to operate, and thoroughly understood. Regional ice data are required where drilling units are clustered together and ice avoidance action such as iceberg towing at one site may endanger another site.

Even though drilling operations in the study area have not been subjected to any serious ice-related accidents to date, there are a number of problems associated with the availability and reliability of data needed for ice-event predictions, and with the adequacy of ice detection devices in current use.

Icebergs are poor radar targets; the maximum range of detection is limited because of low signal return and short-range detection is limited because of competing sea clutter return. Research using many different categories of radar equipment has produced a very wide range of estimates of the iceberg detection capability of those instruments. It has been found by a number of researchers that, visibility permitting, most icebergs will be seen before marine radar detects them, and that icebergs of all sizes, but particularly growlers, quite often go undetected.

Imaging radar (Side-Looking Airborne Radar and Synthetic Aperture Radar) because of their all-weather, day and night capability, have proven to be very valuable reconnaissance tools, even though there is considerable confusion regarding their true detection capability against what are essentially point targets. One limitation of Side-Looking Airborne Radar which may prove problematic in a high-traffic area such as the Grand Banks, is the difficulty it has in differentiating ship versus iceberg targets. A positive feature is that it is an ideal instrument for the reconnaissance of sea ice, since it can classify ice type and provide accurate positional information on, for example, multiyear floes in the middle of a pack of relatively harmless first-year ice. Testing and evaluation of these and other sensing devices is ongoing.

A major problem on the Grand Banks is the poor visibility which limits the effectiveness of both airborne visual reconnaissance and long-range visual observation from surface vessels. Rough sea conditions also frequently restrict the movements of support vessels thus reducing their capability to perform reconnaissance work when it is most needed. Information provided by support vessel crews is not always reliable since there are no trained ice observers on these vessels.

Individually, then, each method of ice detection (airborne and shipborne, visual and radar) has its shortcomings. In general terms, for long range strategic reconnaissance upstream from a drill site, combinations of both airborne and ship-based visual reconnaissance along with Side-Looking Airborne Radar have been used; for short range tactical monitoring a combination of marine radars and visual observations from drilling platforms and service vessels are used. Even with the integration of all these methods, small targets may still slip through undetected, particularly during storm situations when detailed and accurate information is most crucial.

■ *OPERATING REGULATIONS* Design and construction standards for vessels, including MODUs, which operate in ice-infested waters have been developed by classification societies, largely for insurance purposes. The *Arctic Waters Pollution Prevention Act*, and the accompanying *Arctic Shipping Pollution Prevention Regulations* specify the design and construction standards required for vessels operating north of 60 degrees north latitude. These regulations divide the Canadian Arctic into ten geographical regions and stipulate at what time of year a certain class of vessel can enter a region.

The proposed *Interim Standards for the Design, Construction and Operation of MODUs*, recently issued by the Canadian Coast Guard, requires the calculation of ice and snow forces and the effect of ice and snow accumulation on the unit's structure, but they do not specify the method or degree of accuracy required in making these calculations. The "Interim Standards" also require that total ice loads be calculated for 100-year return events, but this report has shown that there are not enough data on most ice parameters to calculate realistic 100-year events.

This lack of reliable, long-term data is compounded by the lack of experience of regulatory agencies in dealing with the requirements for exploratory drilling operations in ice-prone environments. Several European countries have specified MODU designs for severe weather operations. These designs include such features as flush surfaces to minimize structural icing, covered work areas, and emergency

assembly areas, and in some cases, "ice strengthening", although it is not clear how effective such reinforcing would be in the event of a collision with glacial ice. Some attempts have also been made by the Newfoundland and Labrador Petroleum Directorate and the American Bureau of Shipping to relate design criteria to ice conditions. Theoretical studies have shown that the damage which a small, undetected piece of ice is likely to inflict on a MODU could be more severe than that described in the Interim Standards. Again, however, no large scale experiments have been carried out to confirm initial findings.

Very little consideration has been given by regulatory agencies to the operation of exposed emergency equipment such as lifeboats and launching mechanisms, under freezing spray or precipitation conditions, nor is it clear from regulations whether lifeboats or life rafts could operate in loose pack ice without a significant risk of hull puncture.

■ *CONCLUSIONS* In general it can be concluded that ice alone will rarely constitute a hazard to offshore exploratory drilling and support operations, providing good ice management procedures are in place and followed. Nevertheless, ice combined with other factors, such as bad weather or mechanical failure, may constitute a risk to offshore operations.

The study has identified a number of gaps in our knowledge of icebergs. The most significant is associated with assessing the probability and consequences of a growler, bergy bit or small iceberg colliding with a structure during severe weather situations. All aspects of this problem are poorly understood including: the frequency of occurrence of these icebergs; methods of detecting and managing them, particularly in severe weather; the motion of these bodies in high sea states; and the results of an impact with a structure or vessel.

Because current operating procedures in the study area call for the drilling unit to move off the site if sea ice is encroaching, and because sea ice is fairly easy to detect, this factor does not pose a threat to human safety.

Although superstructure icing on drilling platforms and supply boats has not been a major problem in the study area to date, there is a need to define the maximum ice loading on platforms and ships and the effect that these ice loadings have on stability and on the operation of safety equipment.

The organizational structure and operating ice management procedures in current use provide adequate insurance against ice-related hazards in the study area. Significant improvements have been made over the past three years for operations on the Grand Banks. Research and development are proceeding on a number of fronts, and operations personnel are gaining expertise in the deflection of icebergs and in streamlining alert and abandonment procedures. A government-initiated collaboration was established to coordinate overall ice reconnaissance and management performance. There is wide recognition of a continuing need for ice detection and surveillance system research; for the establishment of a consistent physical environmental data base; for more carefully researched regulations and guidelines; and for the review and standardization by a joint government and industry management group of ice detection and control procedures used within the study area.

MARINE CLIMATOLOGY

A Review of the State-of-the-Art in Marine Climatology on the East Coast of Canada
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The majority of work in marine climatology in Canada is done by the Atmospheric Environment Service (AES) of the federal Department of Environment. The AES participates in data collection, quality control and archiving, and instrument development as well as the provision of climate information and expertise, and applied climate research. Oil industry activities related to climate largely parallel those of government in data acquisition, archiving and system development; however, many industry studies are site-specific and proprietary. Actual data used in marine climatological studies are derived from many sources including transient ships, weatherships, drill rigs, buoys, land stations, and hindcasts. Data obtained from these sources vary widely in quality, quantity, and applicability. Quality is affected by the instrumentation used and by the training and motivation of the observer. Spatial coverage of marine areas is poor. Land stations, buoys, and weatherships are few in number; drill rigs are limited to specific areas; and transient ships tend to follow well-defined shipping lanes. Temporal coverage is very good for land stations and weatherships but again, variable from other sources. As yet, satellite data bases are inappropriate for any climatological analysis, due to their short term and the sporadic nature of their coverage.

To overcome these deficiencies, hindcast data have been produced, particularly for wind. Hindcast data are synthesized from historical records such as surface pressure and upper air weather maps, using theoretical models of the atmosphere and ocean, and then verified against quality surface measurements. Hindcasts are the most frequent source of data for such applications as design studies and wave models since all other data sets lack the temporal and/or spatial coverage to be widely applicable. These hindcast data are produced on a grid for periods of 20 years or more. This is ideal for many climatological applications, including persistence and extreme value analyses, and examination of spatial and temporal variability. Limitations in grid size, however, may allow important small-scale features to pass undetected.

■ *WIND* Knowledge of wind speed, direction, profile with height, and character (for example gustiness) is very important to an assessment of hazards to safety. The wind exerts considerable force on drill rigs, supply vessels, and aircraft. Since this force is proportional to the square of the wind speed, extreme winds are especially critical. The wind speed alone will probably not be sufficient to affect the survivability of either rigs or supply vessels, but may be critical to helicopter operations or rescue procedures. High winds can also create dangerous working conditions for personnel on exposed decks. In addition to its independent effects,

the wind is also the major forcing factor in generating waves, which usually produce the predominant loads on offshore structures, and is a major factor in wind chill, spray icing, and mechanical turbulence.

Although wind is the most widely studied of the climatological parameters under consideration, much of this work has been oriented toward the wave generation problem and not toward the stresses of the wind itself on structures. Very little research has been done on describing the vertical profile of wind in the marine atmosphere, particularly at anemometer height, which in the case of rigs, can be up to 100 metres above the sea surface. Other areas that have received little study are the determination of gust factors over the ocean; the potential effects of the wave field on the winds; the relationship between rig-measured winds and the true overwater wind field; the optimum averaging time for wind measurements at sea; and refinements in the calculation of extreme or design winds. In general, the present data base of wind information is insufficient to define adequately the temporal and spatial variability of the wind field, the effects of structures on the wind field, or the extreme values to be expected.

In an attempt to delineate an accurate marine wind field, there are areas of disagreement relating to the analysis of wind data which should be resolved. It is not certain, for example, what averaging period is desirable for marine applications. One-minute means have been the standard for years. The World Meteorological Organization has recommended the adoption of ten-minute means while designers may prefer a number which is the highest one-minute average in an hour. The commonly accepted reference height for winds over the ocean is 19.5 metres, yet relatively few wind observations are actually made at this height. The empirical adjustment of other measurements to this standard height may lead to inconsistencies in results.

A program should be initiated on and around several drill rigs to measure the variability of the wind in space and time and the effect of the rig on airflow. Experimental turbulence measurements should also be a part of this study. The utility of high frequency radar and bottom-mounted acoustic sounders for wind measurement should be considered or continued for Canadian waters. In addition, studies should be initiated to produce relationships between wind speeds taken for several averaging periods from one second to six hours. Wind measurements from various reference heights should be compared for a variety of stability conditions and wind speeds to develop wind profiles for several areas so that standard reference heights and averaging periods can be established. Work is necessary to review extreme value analysis techniques and data bases for wind on the East Coast, in order to produce acceptable design wind speeds and to determine the effects of the wave field on the wind field.

■ *ICING* Ice accretion poses a hazard to drill rigs, supply vessels, and especially helicopters. Few measurements exist of icing over the ocean, particularly with respect to its vertical distribution, thus it is difficult to verify existing methods for producing icing statistics or to develop new techniques. For atmospheric icing, most of the present techniques were developed over land, so their applicability to the marine environment is unknown.

Freezing spray is the most dangerous source of icing, accounting for 89 percent of ship icing cases. Combinations of spray and precipitation accounted for a further 8 percent. Because of the lack of observed data on freezing spray, most climatologies and design studies are based on hindcasts of "freezing spray potential", using one of several empirical techniques. These models relate atmospheric and oceanographic parameters to icing rates. Some models use only wind speed and air temperature. Other models also include sea surface temperature, wave height, and salinity. Icing rates are usually given in classes of light, moderate, and heavy or severe, since the actual rate of icing depends on the course, speed, and

structural characteristics of the ship.

Because icing poses serious safety problems offshore, it should be a priority area for the development of new programs. Each of the three icing types (sea spray, precipitation, and rime or cloud) should be studied to determine the vertical distribution; the occurrences and rates should be compared against meteorological and oceanographic conditions at the time of occurrence. Existing techniques for icing forecasting and hindcasting can thereby be evaluated and new techniques developed if necessary. Estimates should also be produced of the total amount of accreted ice due to the occurrence of each type of icing which may accumulate on structures, either independently or in combination, so that the effects of realistic maximum loads can be studied.

■ *SEA SURFACE TEMPERATURE* Sea surface temperature is subject to considerable spatial variation, particularly in the vicinity of the Gulf Stream/Labrador current interaction zone. The present density of observations from conventional sources is inadequate to describe the complex nature of these patterns. The accuracy of sea temperature measurements from ships or drilling rigs is greatly limited by variations in methods, water depth, and adjacent heat sources.

Present satellite systems are able to produce reliable estimates of sea surface temperature within $\pm 0.5°C$. The sensors employed, however, are passive infra-red radiometers, which do not have the ability to penetrate cloud. The next generation of sensor is the microwave radiometer, which will not be affected by cloud, but which involves a considerable reduction in spatial resolution. A combination of data from the two satellite sensors may prove to be the optimum solution for analysis. Climate analysis of sea temperature is not possible at present since there is only a limited archive of radiometer data and no archive of microwave data.

■ *AIR TEMPERATURE* Methods of measuring air temperature on board ships or drilling rigs are limited by siting problems involving instrument height and heat sources. Air temperature is not usually subject to large variations in a given area of the marine atmosphere. Therefore, a few observations, if well distributed, can describe a large area of ocean. Exceptions occur in the vicinity of coastlines, fronts, and the Gulf Stream.

■ *ATMOSPHERIC PRESSURE* Atmospheric pressure is not itself a hazard to safety, but it is a very important parameter. In real time, it is essential for the preparation of the weather charts from which weather forecasts are produced. It is also necessary for the altimeter settings for aircraft. The same analysed surface pressure chart which is used for forecasting is used later in wind/wave hindcast studies. The ability of the hindcast to represent adequately the overwater wind depends on the accuracy, and temporal and spatial coverage of the barometric pressure.

Most ships and all rigs, land stations, and automatic stations report pressure as a basic element. At land stations, the pressure is usually measured with a mercury barometer. Other reporting systems tend to use aneroid barometers.

Pressure is a parameter measured relatively easily and inexpensively by drifting buoys transmitting to satellite. Measurements are, in general, accurate; however, more observations are necessary in data-sparse areas. Drifting buoys would provide additional information which would enhance rig safety, both in the climatological sense, through design, and as a forecast aid through increased resolution of storms and advanced warning in an area where significant storms can form and move rapidly.

To improve this situation, drifting buoys, measuring a few parameters such as atmospheric pressure, air and sea temperature, should regularly be deployed along the East Coast. Moored buoys, similar to those now operated by the United States, or a suitable Canadian alternative, should be deployed on the Scotian Shelf and Grand Banks.

■ *TURBULENCE* Turbulence is not usually measured but is computed through empirical techniques as a gross estimate from wind speed and air/sea temperature difference measurements. Instruments are available which will measure the actual wind motions in three dimensions for short time resolution. It is unrealistic to consider this type of instrumentation for a ship, and unnecessary since most ships do not support aircraft operations. Such instrumentation would, however, provide useful information for both design and real-time applications, if mounted near the helipad of a drill rig. Turbulence measurements cannot be extrapolated to other rigs, since the disturbance of the wind field will vary substantially depending on rig structure.

■ *STORMS* Storms are obviously a major factor in consideration of offshore safety. Many investigations have dealt with frequency and tracks of travelling low pressure systems, including tropical storms and hurricanes. Most of these studies are derived from sets of historical weather maps, in either original or digital form. These maps frequently suffer from a lack of data, particularly in areas with significant ice cover. This may result in poor estimation of the location, intensity, and motion of storms, and may cause storms to be missed altogether. This is particularly true of severe small-scale storms known to occur off the East Coast of Canada.

In recent years, satellite information has aided greatly in the detection and location of storms. Future satellite systems, with capability for wind field determination, will further aid in this regard. Buoys have also aided in storm detection. Deployment of multiple-sensor moored buoys and pressure-sensing drifting buoys in data-sparse areas would also be of considerable utility, as would automatic stations in remote land areas such as the northern Labrador Coast. Such additional information would not only improve the climatology of storms but would be of value in real time for storm warnings and as input to operational weather forecasting.

■ *CLOUDS* Two aspects of clouds are particularly significant in marine climatology, the total cloud amount and the ceiling height (the altitude at which the total cloud cover is at least five-eighths). Automatic stations and satellites have the capability of determining cloud amount and height, although the satellite systems to determine cloud bases are still developmental. Some automatic stations have ceilometers, (light systems which measure the altitude of the cloud base). In order to improve data collection on cloud ceilings, preferred locations for fog, and general visibility conditions, shipboard automatic stations should be placed on ships and rigs whenever possible.

■ *RAINFALL* Rainfall observations at sea are mostly visual estimates, categorized as light, moderate, or heavy. The present data base of information on rainfall rate is adequate in southern areas, since there are numerous land stations with recording rain gauge installations. The gauge at Sable Island, in particular, gives a good estimate of design rainfall for the Scotian Shelf. Similarly, there are several sites on the periphery of the Gulf of St. Lawrence which can be used for design values. For Newfoundland waters and areas farther north, however, gauges are few, and the results cannot be reliably extrapolated to offshore areas, since much of the precipitation is induced or modified by the surface geography of the land.

A few drill rigs have recently begun to measure six-hour rainfall amounts, but these observations are not included in the digital archive. The data produced, although the best presently available, are also of questionable quality due to the difficulty of finding an unobstructed location for the gauge. There is very little information on the short duration, high rainfall rates which are likely to affect deck drainage and the quality of radio transmission.

■ *CONCLUSIONS* The primary factor inhibiting our understanding of the marine environment is a general lack of baseline data for all parameters. As a result, many important analyses cannot be performed, and some that are done are of question-

able quality. Correcting this situation would involve improved data acquisition through the development of new or expanded programs.

Satellite systems capable of measuring atmospheric and oceanographic parameters should be supported. Of particular importance are wind measuring scatterometer systems and microwave sensors for sea surface temperature. Satellite-derived data should be archived in digital form. Existing hindcast data sets should be evaluated against quality measured surface data. If no suitable hindcast sets can be identified, a new Canadian hindcast should be produced. Networks of drifting buoys would provide pressure data essential to the analysis of surface weather maps on which hindcasts are based, in order to describe accurately the location and intensity of cyclonic storms. These improved maps would also benefit weather and wave forecasting. Shipboard automatic stations should be implemented wherever possible on ships and rigs; and automatic stations reporting through satellites, should be set up in remote coastal locations.

Very little work has been done on effects produced by combinations of factors. It may not necessarily be the maximum values of these conditions which cause the maximum loadings. Resonance conditions or differing stabilities may result in some other combination of factors being more critical. Occurrence of low visibility in conjunction with high winds or waves, for example, may pose problems that the independent occurrence of either would not. Various combinations should be considered for critical operating ranges, and joint frequencies computed.

The ramifications of weather conditions at supporting land stations have had minimum study. These conditions may affect operations or, more critically, emergency response capability. The occurrence of severe conditions which might require evacuation at a rig should be correlated with conditions such as flying weather (ceiling, visibility, icing) at the nearest search and rescue locations. Consideration of flying weather at supporting land stations is important at all times since potential evacuation is not restricted to severe weather occurrences at the rig. Studies of the persistence factors should be incorporated into plans for all proposed support locations.

Published climatologies, contingency plans, and impact statements are usually limited to frequency information on a few basic parameters. In order to properly assess and describe potential hazards to human safety, additional analyses should be performed including:

- Persistence, extreme values, and gust factors of winds;
- Persistence analysis of low ceilings and visibilities;
- Frequency and persistence of icing conditions for each of the three icing types;
- Frequency of thunderstorms and heavy rains;
- Minimum and maximum air temperatures, persistence of high and low values, wind chill frequency and extremes;
- Statistical summaries of cyclonic storm distribution, frequency, persistence and intensity;
- Joint frequency distributions of hazardous combinations of conditions, such as high winds and low visibility;
- Frequency and persistence of adverse weather conditions, particularly flying weather, for all supporting land stations, both independent of, and combined with, adverse weather conditions at drill sites.

WEATHER FORECASTING SERVICES

Weather Forecasting Services for the Canadian Offshore
Part 1: Organization of Responsible Agencies and Current Practice
Part 2: Assessment of Adequacy
Seaconsult Limited
St. John's, Newfoundland
August 1984

■ *ORGANIZATION* Traditionally the Atmospheric Environment Service (AES) has been responsible for weather forecasting throughout Canada. Their jurisdiction includes marine and aviation forecasts in addition to forecasts for general public use. Under offshore drilling regulations, operators are required to contract location- and route-specific weather forecast services. In the eastern Canadian offshore these services are provided by private corporations catering specifically to this need. These firms are required by regulation, to have personnel trained to AES standards. All of the agencies involved are therefore tightly linked and the forecasts they deliver are highly similar. Prognoses are based on the same cascade of information from within the AES organization, and they approach weather forecasting using the same meteorological principles and equipment.

Despite the fundamental similarities among forecasts, the presentations offered by private versus AES sources do differ. The private forecast firms have tended to adopt rather scientific formats for presenting wind and sea state parameters as a function of lead time in six-hour increments. It is tempting to ascribe an "observational" accuracy to these predictions, and to treat them as being more accurate than they really are. As shown by verification results on quantitative element forecasts for storms (wind, sea state, visibility) there is a gradual reduction in forecast ability up to 24 hours lead time that then steepens to become a major decline after 48 hours. As a result there is considerable uncertainty associated with the long-range parameters, especially at lead times greater than two days, which must be taken into account in the use of these forecasts to make decisions controlling offshore operations.

The meteorological and sea state parameters or elements that presently form the basis of forecast data are: wind speed and direction, sea wave heights and periods, temperature, pressure, visibility, and freezing spray. These parameters are presented in descriptive and/or numeric terms to cover an area or a point in the ocean, at regular increments of time or valid periods which are usually 6 or 12 hours apart.

■ *CONTENT* The information level of current forecasts is very low when one considers how much prognostic data have been distilled to produce them. One example of how the information content could be increased relates to wave spectra. Sea state parameters are usually specified as a wind-sea and two swell components. These are added up to give a "combined" sea wave height, period, and direction. There are no parametric hindcast procedures which truly model the physics of old swell seas, and to date, large-scale discrete spectral wave models,

which would approximate the propagation of swell components, are not used in Canada for wave forecasting. Therefore, the two forecasted swell components are largely meaningless and about the best one can do is interpret the combined sea height as roughly equivalent to a significant wave height averaged over the valid time of the forecast. Thus the sea state forecasts issued by private firms actually contain the equivalent of one wave height and period, and a rough indicator of direction to represent a given location at sea. The maximum wave height is just a statistical extrapolation of the first value and does not increase the information contained in the forecast. This prognosis is updated every six hours. During a storm these are the minimum data requirements for assessing the expected motion of a floating drilling vessel. A more reliable motion analysis would be obtained from predicted wave spectra computed with two-dimensional models on a one-hour time step. Such spectra would resolve crossing seas and rapid changes in wave growth as the storms peak over specific locations. Thus the presentation of spectra, properly computed as opposed to wave height and period would provide a significant increase in the information contained in sea state forecasts.

Other limitations in content of current forecasts are a result of gaps in available forecast technology. For reasons based on the sparseness of observing points over the ocean and incomplete understanding of atmospheric physics, forecasts deal with changes in weather on synoptic scales, over distances exceeding 200 to 300 kilometres and durations of 2 to 3 days. Smaller mesoscale events, occasionally producing the most severe, albeit short-lived conditions, are not encompassed in the preparation parameters. Increasing the information content and thus effectiveness of forecasts by, for example, including wave spectra or mesoscale atmospheric processes, would involve fundamental changes to present data acquisition and presentation techniques.

■ *PRESENTATION* Forecasts are presented in a very rudimentary manner with all parameters given equally for the same lead times, and transmitted over telecopier circuits or broadcast. For users receiving analysis charts and satellite imagery over photo-facsimile machines, prognoses can be supplemented with current information on the spatial structure of weather systems. There is little use of colour graphics displays showing two-dimensional prognoses blended with observational data such as satellites and weather radar images. A computerized system of forecast dissemination, given present-day transmission capabilities, would make it possible, for example, to show the dynamic behaviour of storm systems in the past and projected into the future, to isolate and predict some small scale events within them, and to present both area and site-specific forecasts rapidly and interchangeably. This procedure would allow short lead-time prognoses with detailed information to be sequenced with longer lead-time, less detailed presentations.

■ *VERIFICATION* Verification of marine forecasts given by private firms is a well established procedure which provides a great deal of information about forecast quality. Current programs, however, tend to be statistical and remove the connection between storm history and the nature of forecast errors for severe events. Routine verification of forecast performance using time series analysis techniques to show the relationship between magnitude and timing errors would also be of value. Useful, too, would be an analysis of the consequences of various kinds of missed events on offshore operations, for example the storm peak predicted too early or too late by several hours. Because forecasting is based upon manipulation of observed or forecast synoptic weather systems, post-mortem analyses of particularly difficult events, together with a formal mechanism to transfer the experience so gained to all forecast personnel, would be valuable and must receive more attention. The intent should be to improve procedures and "build in" this information.

■ *ASSESSMENT* Operator experience in eastern Canadian waters has long since revealed those adverse weather conditions that pose a threat to human safety. Two are particularly important: severe winter storms that would endanger the rig and its entire crew, and fog that makes helicopter operation hazardous. These two situations demand very different types of forecast information.

Operators require long-range forecasts of severe winter storms to carry out specified procedures for securing the well, and for securing or evacuating the drilling unit. Long-range forecasts are provided that describe weather elements including winds and sea states with sufficient lead time and resolution. The communication of information is effective and timely because of the personal briefing methods used, especially during alerts. Element forecasts beyond 12 to 18 hours, however, tend to be uncertain. This means that the prediction of whether a storm will produce site-specific winds exceeding certain thresholds is also uncertain. The practice adopted to deal with this uncertainty is to monitor the storm development, from perhaps 48 to 72 hours down to 18 to 24 hours lead time and in this way obtain the best possible estimate of the need to evacuate the rig.

The consequence of this monitoring may well be the loss of safe evacuation time for all personnel. The fall-back of leaving personnel on board the drilling unit must then be adopted. There is some variation among operators in their stated approach to this problem of how long to monitor since evacuation is both expensive and with some danger of its own, and storms producing winds exceeding 85 knots are extremely rare. Although variations from storm to storm must be expected, the situation described above is likely to represent the worst case, that of the winter storm so severe that it, by itself, poses the hazard. Even in these circumstances, however, the tactic of securing the well and the rig, and leaving personnel on board to wait out the storm is considered by the operators to be an acceptable approach to ensuring human safety. Moreover, it meets regulatory expectations for safety at a perceived acceptable level of risk. Since the weather forecasting services provide the information needed to carry out the response plans, and those, in turn, are accepted as the means of ensuring safety in storms, then the forecasting services are adequate as presently available.

■ *HELICOPTER OPERATIONS* Helicopter flight planning requires accurate wind speed and direction, and terminal visibility prognoses so that fuel and payload can be optimized while providing an acceptable safety factor on a round-trip without refueling. These forecasts are provided to the pilots by AES, using personal briefings in the presentation offices. Communication between the pilots and the AES presentation personnel is excellent. The people involved on both sides are experienced in weather needs and the peculiarities of forecast marine data, and allow a margin of error in their decisions.

The timing of the weather forecast information available to the pilots presents a problem. The shift to daylight saving time in Newfoundland and the scheduling of flight departures from St. John's before 07:00 Newfoundland Daylight Time (NDT) may lead to the use of marine forecast data issued at 00:30 Greenwich Mean Time (GMT) or 22:00 NDT, instead of the more current 06:30 GMT forecast. The synoptic description, and the wind and visibility prognoses may therefore be inaccurate. This situation could be remedied most easily by delaying departures from St. John's until about 09:00 NDT, or by improvements in data transfer to pilots at this time of day. On balance, present forecasting services are considered adequate for helicopter operations during the fog season.

■ *FORECAST ADEQUACY* The examination of weather forecasting services to the operators conducting exploratory drilling programs has shown that the needs of the industry to ensure human safety are being satisfied. Emergency response in the face of major storms, whether complicated by well, rig or ice problems, is technically and logistically complex. The facilities put in place by the industry ensure

that the kind of weather forecast data needed for decisions on securing or evacuating the rig are available. Moreover, clearly defined response procedures recognize the limitations in forecast data and attempt to deal with these in the most rational manner.

The major limitation with forecast weather data is the reliability of specific elements such as wind speed or wave height. Improvements in prediction accuracy are constantly being made in national weather services in both Canada and the United States, and these will benefit industry as they come into operational use. Weather forecasting is a very complex science, involving a great deal of human experience and judgement. Agencies now providing these services are working at the state-of-the-art; there are no serious gaps between national services in Canada or the United States and the private forecasting firms contracted for site-specific data by the operators. It appears that operating oil companies are obtaining the best information available.

■ *AREAS OF IMPROVEMENT* There are a number of areas where improvements could be introduced into the system and these could be expected to yield benefits in terms of more accurate forecasts, or more confidence in dealing with hazardous weather.

Success in storm forecasting over marine areas depends on timely, accurate data. Improvements in element forecasts would be expected from the deployment of tethered buoys that telemeter pressure, temperature, and possibly wind data via satellite. More reliable short-term (up to 24 hour) forecasts over the drilling areas would result from buoy deployments in Canadian waters; this has been demonstrated by an experimental program organized by AES in the winter of 1983-84 off the East Coast. Increased accuracy in long-range storm predictions (24 to 48 hours) would also be expected by deploying buoys along the eastern U.S. seaboard; these would give earlier and better definition of weather system behaviour before it reaches Canadian waters. Parallel improvements in monitoring upper air winds would also increase the accuracy of predicted storm trajectories and hence site-specific winds. These "upstream" data would be of great value to the numerical weather prediction models that are so important for long-range prognoses.

Monitoring programs of this nature are costly and logistically complex, both for instrument servicing and ensuring that data is properly entered in the distribution network. They are probably best approached by a joint government/industry program recognizing the benefits to accrue to all marine forecast users.

Forecast presentation methods need improvement. Weather-related emergency response plans call for the active participation of the person in charge of the drilling unit and the drilling superintendent. Offshore personnel must rely on a combination of their own judgement and the weather interpretation given from shore by voice contact. Forecast data may be received on the rig in a variety of hard-copy formats. The offshore personnel must either sort through these transmissions and interpret them for a broader understanding of events to come, or rely strictly on the element forecast provided by the contracted firm, which gives a much more restricted picture. The crew often copes with this situation by expecting the contract weather observer to function as a forecaster, a role for which he generally has no qualifications.

These problems could be eliminated by upgrading presentation technology and bringing the drilling unit personnel in voice and image contact with the forecast office on shore. At a first level, existing television technology could be used simply to relay data and communications. At a more advanced stage, digital image processing and manipulation software could portray storm formation and predicted developments, and element forecasts, all interfaced with two-way communications. The purpose would be to condense information going to the rig into its most meaningful forms, and ensure consistent information flow between the

forecaster, the emergency coordination office on shore and the drilling unit. It would also remove the need for inappropriate demands on the observing personnel.

During interviews with marine crews and environmental coordinators, a desire for more training was noted. This could take the form of dedicated short courses covering weather elements, sea state, ice and currents that are pertinent to eastern Canadian waters, methods of forecast preparation and dissemination, monitoring equipment and response procedures. Marine crews commented that they have some training in meteorology and waves, but that it is too general, giving a global picture rather than characteristics of a particular area. Responsible personnel within oil companies felt benefits would follow from specialist briefing in all environmental factors affecting operations.

Presently, verification at the Canadian Meteorological Centre is done on all forecasts using SI scores which provide only an averaged indication of performance. Overwater element forecasts should be verified in a time-series manner, adopting a common procedure with the private firms to establish how accurate the 24- to 72-hour forecasts are, and to identify those weather systems that are difficult to forecast with certainty. A better understanding of long-range prognoses, between AES and its users, would be one result of this process.

Consistent forecast verification procedures are lacking between private firms, and the various levels of AES. Private forecast companies could extend their present procedures to look at more storms on a case-by-case basis in time-series format. This would reveal whether errors in predicted parameters were due to poor estimates of weather system intensity, position, speed of advance, or some combination of all three. The current statistical approaches do not easily allow this type of diagnostic examination.

Currently many countries provide sea state predictions using advanced spectral models coupled to their numerical weather prediction systems. Canada does not do so, relying instead on parametric significant wave height models. Forecasting services in this country now give wave heights associated with swell and wind sea, their directions, and a combined maximum wave height. It has not been clearly demonstrated that for this level of information, the more elaborate spectral models give more accurate results. Operators, and particularly marine crews on the drilling units and supply boats have expressed a concern about receiving complex wave information that they would have difficulty understanding. In fact, the opinion was that the parameters presently available were quite adequate for their needs, being both familiar and "reasonably accurate".

Spectral sea state modelling, routinely linked to numerically predicted wind fields, is beneficial to offshore exploration, if not in extending forecast parameters now, then in terms of its other advantages. These include: a physically more correct and accurate treatment of swell; a physically more correct procedure for propagating storm waves in concert with the generating weather system (crossing sea prediction); and a climatological data base that accumulates from the analysis fields, which would extend knowledge on wave conditions into presently deficient areas. For these reasons, and for the benefits to users other than operating oil and gas companies, advanced wave generation models should be seriously considered for eastern Canadian waters.

WAVE CLIMATOLOGY

An Assessment of the State of Knowledge of East Coast Offshore Wave Climatology
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W.F. Baird, W.F. Baird and Associates
Ottawa, Ontario
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A wind-generated wave field propagating over the oceans is an extremely complex phenomenon which is not well understood and can only be described by numerical methods that involve many simplistic assumptions.

Waves are formed by a complex interaction between turbulent wind and the water surface. Their growth is governed by speed of the wind, length of time that it blows, and distance (fetch) over which it blows. There is almost no mass movement of water associated with the propagation of waves except when a wave breaks. A small object floating on the surface describes a circular path as the wave moves past; the diameter of the circle is equal to the wave height and the time required to complete the circle is the wave period. An individual wave is not permanent; it slowly increases in height and then decreases as the wave moves forward.

Locally generated wind waves do not all move in the same direction, but the directions will lie within 45 degrees either side of the mean. As waves move out of the influence of the wind that generated them, they tend to increase their period and become long crested. These waves are known as swell. The slope, or steepness, of the leading side of the wave may be steeper than that of the rear side. If the front slope becomes steep enough, a breaker forms (a mass of foaming water moving down the front face at a speed greater than that of the wave itself). In very severe sea states, waves may reach heights of at least 40 metres, periods of 18 seconds, and lengths of 500 metres. Swell waves can have even longer periods and wave lengths, but the heights will be lower.

There are many organizations associated with offshore exploration for oil and gas who have an interest in wave climate: the operator, drilling contractor, rig designer, builder, classification society, regulatory agency, consultant, and research laboratory. To get an appreciation of their particular concerns in respect to wave data, a review was conducted of published material, especially design manuals and classification society rules and standards. This was followed up with interviews and/or correspondence with organizational representatives. All discussed the need for improved or additional data in Canada. The urgency with which the data should be obtained depends on the location under consideration, the type of structure and the responsibilities of the organization. None of the design, classification or regulatory agencies identified any limitations of existing methods for obtaining wave data, of analysing wave data, or of applying wave data to design procedures that lead to unsafe structures, structures that are significantly overdesigned, or problems with operation of these structures. Research

and development in the area of wave measurement and prediction, and wave-structure interaction is continuing but without a sense of urgency.

The best achievable values for the maximum wave height and its associated period to be expected in a given return period, typically 100 years, are needed to determine the motion response of structures, the stresses produced in their components, and the maximum crest elevation to provide for underdeck clearance. In the analysis of fatigue in rig components, it is necessary to have bi-variate frequency of occurrence, that is, scatter diagrams of typically significant wave heights and peak periods by direction. Twenty years of records may be necessary. Similar data but based on shorter periods (three to five years) provide for exceedance and persistance statistics and other criteria which are essential to operational planning. All of these statistical descriptions of typical or extreme sea states are essential inputs to modelling studies whether by computer or wave tank.

■ *INSTRUMENTALLY MEASURED DATA* Extensive measurement of waves has been undertaken in eastern Canada since 1970 primarily by the Marine Environmental Data Service (MEDS) of Fisheries and Oceans Canada. Much offshore data has been acquired through cost-shared programs between MEDS and the oil companies operating the drilling units. The instrument used is the Datawell Waverider Buoy, which consists of an accelerometer housed in a floating sphere that is tethered with a single point mooring. The standard products for each location are the significant wave heights, H_s (the mean of the highest one-third of the waves in a record), and the peak period obtained at 3-hour intervals when H_s is less than 4 metres and every 20 minutes when it is greater than 4 metres.

Waverider data have a number of limitations. For offshore eastern Canada, the area covered is limited to drilling sites already occupied and the length of record at each site is too short for reliable statistical estimates of extreme events such as the 100-year significant wave height for which a minimum of 20 years of data is desirable. There are few winter records as yet. Waverider data is of limited value for certain engineering applications where the shape of wave is important because the restraining effect of the mooring results in a distorted record of the surface profile.

Notwithstanding these limitations, the data from this instrument is invaluable for many applications. It has been virtually the only source of objectively measured, site-specific information on waves continuously recorded over months of time and, most importantly, providing coverage of storm events.

There are firm requirements for instrumentally recorded data on wave direction and wave amplitude. Only since 1983 has a buoy that records both parameters been in use, on a trial basis. It will be a long time, at least 20 years, before data from this directional buoy can be used to estimate extreme probabilities. In the short term, these records can provide a check on the accuracy of a hindcast model depiction of a storm event including, in particular, the wave directions at a site.

Remote sensing techniques have been used to measure waves from satellites and aircraft. These techniques are even more recent than the waverider measurement program, and the time series are, therefore, shorter. The techniques involve the use of laser altimeters, scatterometers, and sophisticated radars. To date only the satellite-borne laser altimeter, which produces a wave height value, has been proven capable of providing accurate results on the continuing basis required to develop climatological data sets. The first and as yet only satellite to carry a wave-sensing radar was Seasat launched by the U.S. National Oceanic and Atmospheric Administration (NOAA) which operated for just three months. It produced world-wide coverage of significant wave height. Selected wave data from Seasat have been acquired by MEDS and evaluated against measured waverider data for the times and locations where coincidences of measurement occurred. The results

indicated the Seasat data were accurate to within ten percent, suggesting that similar data from future satellites would be valuable from a wave climate perspective given sufficient spatial and temporal coverage. Several satellites including the Canadian Radarsat, carrying among them a variety of sensors for measuring waves, are planned for launch toward the end of the decade.

■ *VISUALLY OBSERVED DATA* Observations of wave conditions as well as meteorological phenomena are routinely reported from many ships at sea. The wave observations are a visual estimate of the average height and period of the larger well formed waves, roughly equivalent to the significant wave height and period. This data is reported by radio to the appropriate meteorological service, in the case of Canada to the Atmospheric Environment Service (AES). The program has resulted in a data bank extending back many years and covering much of the eastern Canadian offshore. It is the basis of an 11-year wave data set called METOC.

■ *METOC DATA* METOC is derived from significant wave charts prepared twice daily by the Canadian Forces Meteorological and Oceanographic Centre in Halifax. The charts are prepared from ship observations supplemented with real-time waverider buoy data from exploratory oil rigs and coastal locations and data derived from simple hindcast procedures for areas where no real-time data are available.

The METOC wave data cover the North Atlantic Ocean between 25 degrees north latitude and 70 degrees north latitude, excluding the Gulf of Mexico, Gulf of St. Lawrence, and Hudson Bay. The quality of this data set can be considered to be higher than that of the ship observation data from which it has been prepared because of the subjective quality assessment carried out. The analysts compare observations from nearby ships to identify errors and use the previous chart and hindcasting monograms to assess individual observations and fill data gaps.

There are two applications for METOC data. The first is the determination of the wave climate for operational concerns, two examples are that waves would be larger than a given height for 30 percent of the time in February, and that once the waves exceeded 6 metres at a given time of year, they persisted above that height for 36 hours on the average. In areas where there have been sufficient ship reports over the years and throughout the seasons of the year, the METOC data is good for this sort of application. The second use of METOC data is in estimating return periods for extreme events. This process depends on the accurate determination of peak wave heights for all the most severe storms. The METOC data is not as reliable for this application as a carefully prepared hindcast which is a more sophisticated procedure relying on more detailed and accurate historical data sets.

■ *NMIMET DATA* NMIMET is a suite of computer programs developed at the National Maritime Institute (NMI) in collaboration with the U.K. Meteorological Office, for the purpose of synthesizing statistics of wave climates from visual observations of wave height and wind speed, or wind speed alone. In NMIMET a parametric model of the joint probability of wave height and wind speed is used as a best fit function for smoothing and enhancing the quality of the ship observations of waves. Implausible observations are thus suppressed without subjective intervention. The NMIMET procedure has been extensively assessed against measured data in the vicinity of the United Kingdom. The results there were good for the exceedence of wave heights. NMIMET data for three locations in the study area – the mid-Labrador Coast, near Hibernia, and in deep water off Sable Island – gave the following values for the 100-year significant wave height: 14.2, 14.5, and 17.0 metres respectively.

■ *HINDCAST DATA* The wave climate of any body of water, can be described to a reasonable degree of accuracy if the wind field over the water and its time history are known. This is known as hindcasting. Ideally, the calculation requires a numeri-

cal model that simulates the physical processes of wave generation by wind, wave growth and propagation, and the interaction of waves with other waves, currents, and the seabed.

There are two categories of models. The simplest models represent an empirical approach that provides an estimate of the significant wave height and period, or similar parameters, and does not deal in depth with the physics of the problem. The other category includes the spectral models that describe the sea state by a directional variance spectrum. These models may include equations that deal with the spectral energy balance and the transfer of energy between wave periods (wave-wave interaction) and generally involve far more complex computing than empirical models do.

In the simplest models, the wind velocity is assumed to be constant over the generating area, while in the complex models, the wind velocity is input at grid points. The accuracy of the latter is partially dependent on the size of the grid and the time interval between the wind velocity data. The wind data for the grid are determined from pressure gradients, although in some instances, these may be blended with wind measurements obtained by other means.

The U.S. Navy Fleet Numerical Oceanographic Center has produced a 20-year hindcast of the North Atlantic, using their spectral ocean wave model (SOWM). Although this model produces good descriptions of wave climate in the open sea it has two serious faults when applied in the study area. It models the shoreline far to the west of its actual position resulting in unrealistically long fetches for westerly winds. Also, it does not take pack ice into account, so again fetches are too long for winds blowing off the ice. Both faults lead to significant overestimation of wave heights. The SOWM model cannot be considered applicable to the study area.

A wave information study (WIS) for eastern North American coastal waters has been done by the U.S. Army Engineers Waterways Experiment Station covering the same period of time (1956 to 1975) as the SOWM study. It appears that the WIS hindcast benefited from some of the limitations of the SOWM study and the use of a new wave prediction model. The WIS model, however, also doesn't define the shoreline in the study area well enough and doesn't allow for ice. It, therefore, overestimates wave heights, although not as much as the SOWM.

The Oceanweather Inc. hindcast for Mobil Oil Canada Ltd., prepared in 1982, determined the extreme wave conditions required for design of structures for the Hibernia area. This study used a smaller grid than the WIS model thus providing a better definition of the shoreline; took into account the effect of pack ice, when present; selected storms over a longer period (30 years instead of 20); and generally improved input wind data. The result of this process was the development of the best hindcast to date in the study area. Nevertheless, there is a question about the selection of storms used in the hindcast. Since some of the storms used appear to be less severe than the "one-year" storm and since 20 storms were selected from a 30-year period, there is doubt about whether the most severe storms were used.

The Oceanweather Inc. study was verified by comparing the results of the hindcast with waverider data for two storms during which the instrument was in operation. The model predicted a maximum significant wave height of 11.3 metres for one storm and 8.9 metres for the other whereas the corresponding values from the waverider records were 10.1 and 8.7 metres. The hindcast gives a measure of the large spatial gradient in wave climate eastward from Newfoundland; the 100-year significant wave height is shown as increasing from 13 metres near the coast to 16 metres some 200 nautical miles to the east. For the vicinity of Hibernia, the most appropriate value for the 100-year return period maximum wave height was found to be 30 metres, with an associated period of about 16 seconds.

A hindcast done in 1978 for Total Eastcan Exploration Ltd. produced data for four points spaced evenly along the Labrador Shelf. The 100-year significant wave heights ranged from 13.5 metres in the north to 16.3 metres in the south. The major limitation of this study is the small sample of seven years from which extreme events were estimated.

■ *EXTREME VALUE ANALYSIS* Extrapolating time series of a given parameter, to estimate the largest value that parameter is likely to take in a given period of time, is a major theoretical and practical problem. There are two types of procedures in general use today. One fits a statistical distribution function to all observed values in a time series. The log-normal and Weibull distributions are the most frequently used for estimating wave heights. The other type is concerned with the statistics of extreme events in the time series. Observed large values are selected and, typically, fitted to a Fischer-Tippett type I, II or III distribution. In the case of waves, it would be observed storm waves that are selected for the analysis. The underlying objective of the use of extreme value distribution is to develop a description of the total population of all storms (waves) and then reliably estimate the magnitude of the maximum storm wave which should occur in a specified interval of time, for example, once every 100 years.

For the Scotian Shelf, reliable data describing severe storms do not exist but a study supported by the Environmental Studies Revolving Funds (ESRF) is in the process of defining the 30 to 50 most severe storms that have occurred over the area. Studies have also been undertaken to identify procedures for treating wave propagation in shallow water areas such as exist on the Scotian Shelf. Special problems of the Scotian Shelf include shallow water effects, sheltering due to Sable Island, and possibly wave-current interactions.

There has been more work done on the prediction of extreme events on the Grand Banks and particularly in the Hibernia area than anywhere else in the study area. The Mobil hindcast provides the only data that should be considered for extreme value analyses at this time. The questions on the selection of storms in the study should be addressed, and it would be desirable to undertake additional verification of the procedure before the design values are accepted. The ESRF storm identification project will assist in answering at least part of this question. Special problems in this area include the presence of the ice edge and possibly the effects of bathymetry on extreme wave conditions. An in-depth analysis of the effects of bathymetry and currents on extreme wave conditions is required.

There is considerably less information for describing the wave climate of the Labrador Sea than for the southern parts of the study area. The SOWM model must be discounted as a source of wave climate information for the area. The WIS data were not archived for the Labrador Sea north of 53 degrees. The METOC data are probably adequate for operational concerns during the summer-fall seasons when reasonable numbers of ships' reports are available. The most carefully executed analysis for extreme events appears to be the Total Eastcan hindcast; it must be used with caution, however, because only seven years of storms were treated. It would now be possible to undertake a significantly improved hindcast because there are considerable more data than were available in 1976. The ESRF storm identification project should be a start in this direction.

The Gulf of St. Lawrence has been the subject of only one hindcast study and that was for the limited purposes of the Gulf Corrider Project. The data should be of some value in planning and conducting operations but of very limited use for the estimation of extremes. Nevertheless, the wave climate of the Gulf is clearly less severe than that of the open ocean parts of the study area.

There are no measured data and no satisfactory hindcast data for Davis Strait, Baffin Bay, or Lancaster Sound. The wave climate is less severe in these northern areas than in the Labrador Sea because of the presence of ice and the

limited fetch available in most directions for wave growth.

■ *SPECIAL STUDY AREAS* The techniques of wave climate estimation discussed so far assume deep water and thus do not take into account the effect of shoaling on wave characteristics. At a depth of about 100 metres the largest waves begin to undergo transformation involving their height, length, period, speed, and direction. These effects are felt by progressively smaller waves or the water shoals, and they become particularly significant where water depths are less than 50 metres. The Grand Banks and Scotian Shelf have a number of areas shallower than this. An outstanding example is the Venture site where the water depth is only about 20 metres.

The modelling of the transformation of waves moving into shoal water is at an early stage of development and it suffers from the poor state of knowledge about the physics involved. Existing models describing the process are either unverified or verified with limited data applicable in special circumstances. There are no available reports of an analysis of the wave transformation process for any location in the study area.

A number of possible wave characteristics are recognized as having the potential to produce motion or stress responses in a structure that are significantly different from those estimated to occur using analysis procedures with standard wave characteristics. These non-conventional wave events, include non-symmetric wave geometry, breaking waves in deep water, wave grouping, and "freak" waves.

There is evidence of wave assymetry from wave recordings; the average slope on the leading side of a wave is steeper than that on the following side. The steepness on the leading side may be greater than assumed in design procedures and has the potential of producing larger loadings when the wave interacts with a structure.

Breaking of waves in deep water is a manifestation of strong non-linearities of the free surface boundary conditions and is one of the least understood aspects of water waves. Wave steepening and breaking is known to result where waves move into an opposing current and also when non-linear interaction of several waves in a train occurs.

Wave grouping can be observed in many wave records. The larger waves are grouped together rather than being randomly dispersed within the wave record. It has been demonstrated that some structures respond differently to the two wave trains (one with the larger waves grouped together) even though the average or significant wave height for the two records may be the same. The effect is due to two phenomena – a group set-down under a wave group and an associated set-up between groups which leads to the formation of long waves which can excite structural response. This is important in shallower water. The successive occurrences of several large waves leads to excitation frequencies which are related to the group repetition frequency rather than the wave frequencies. This is important for large structures.

The words "freak", "rogue", "episodic", "abnormal" are used to describe very large waves that are occasionally encountered at sea. There are many reports of ships being damaged by them, but there is no theoretical basis to describe their frequency of occurrence. In the presence of a horizontal current gradient, refraction of waves can result in a concentration of wave energy. This can combine with wave steepening that occurs when the current and wave direction are in opposition to produce extremely rough conditions. Many of the ship reports of "freak" waves have occurred in areas where strong ocean currents exist. A notorious area is located near the edge of the continental shelf off southeast Africa where the Agulhas current moving strongly southward and large waves from the southern ocean travelling northward interact to produce very damaging seas. An analysis of

wave interaction with currents that may occur in the study area and the possible consequence of increased wave heights has not been published.

The most serious limitation to research into non-conventional wave events is the lack of prototype measurement of them, that is, a measurement which records their characteristic features with precision and in three dimensions. Rectifying this calls for a program of measurement which should emphasize the following: point measurement of surface profile from a fixed location, as complete a description as possible of directional wave characteristics, continuous recordings during storm events, and mapping of the sea surface at an instant of time (as might be obtained from stereo photography).

■ *CONCLUSIONS* In summary, the minimum requirements of the design, certification, and regulatory agencies are well defined in the available literature. Industry is, in general, satisfied that if these requirements are met, safe, efficient, and effective structures can be designed and operated. The authors have found no evidence to suggest the opposite.

For operational purposes, three to five years of simultaneous measurements of wave, current, and wind conditions are needed. For design purposes, a hindcast of wave conditions during all storms for which reliable meteorological data exist is necessary to define the wind field adequately. These data should cover a minimum period of 20 years.

These required data are not available throughout the study area. Adequate estimates of the wave climate for operational concerns exist only in some of the southern areas. There are no values of extreme wave conditions for any part of the study area which can be accepted without further analyses. The values produced for the Hibernia area in the Mobil Oil hindcast appear to be the best available at the moment, but it only estimates extremes and not wave climate and it is limited to a small geographical area. Much of the complex data required by research organizations has not been acquired because of the extreme difficulty in measuring the necessary parameters or because suitable instrumentation is not available.

Wave data must be developed in the near future that will be suitable for the accurate estimation of extreme conditions in selected parts of the study area. The urgency of this requirement in the case of exploratory drilling may be somewhat less if units having unlimited class are used or if conservative assumptions are made. In the case of production facilities designed for the wave climate at the location where they are to be used, this requirement is of the highest priority. It could best be accomplished through a joint program by all organizations requiring the data.

Wave models are needed which are capable of describing the behaviour of waves in shallow water and the interactions of waves with currents. These should be subject to verification of field observations from sites in the eastern Canadian offshore. Further development and field testing remains to be done on instrumentation to measure the directional properties and profiles of waves.

Satellite-borne systems of remote sensing will be an important source of wave data in the future. It is important that progress in that field be monitored and that suitable actions be taken to incorporate the data into wave programs as soon as it becomes advantageous to do so.

Simultaneous measurements of waves, currents, and winds are required in areas where drilling programs are concentrated. Wave data collected with corresponding if conservative assumptions are then made. In the case of production facilities designed for the wave climate at the location where they are to be used, this requirement is of the highest priority. It could best be accomplished through a joint program by all organizations requiring the data.

OCEANOGRAPHIC INFORMATION

Oceanographic Information for the Eastern Canadian Offshore: Adequacy for Exploratory Drilling
Seaconsult Limited
St. John's, Newfoundland
August 1984

Currents in the sea may affect drilling operations by increasing loading on the rig, interfering with downhole or diving operations, transferring sediments, and increasing or decreasing wave steepness. The dominant characteristics of currents are variability and the multiplicity of space and time scales over which they occur. At the largest scales and longest periods (several tens of kilometres and days to months) the important influences on sea motion are seasonal changes in weather and runoff, and variations in topography. At slightly smaller scales, storm winds, meanders and eddies all contribute to displacing and changing the large-scale currents that affect a given site. At scales of a few tens of kilometres and periods of a few hours to about one day, tides and storm-generated surges are present. Both bathymetry and local stratification play major roles in modifying these flows. At the smallest scales, of a few hundred metres and a few minutes in time, internal waves account for most of the fluctuating motion. In places these waves may have very large amplitudes and generate strong currents.

Instruments, analytical techniques and some predictive models are geared at resolving and explaining some but not all of these scales. This situation affects two aspects of the problem. First, in order to estimate extreme currents, one must be able to predict how variations, ideally over all scales, combine to give the worst flow condition at a known probability of occurrence and with some acceptable confidence. Second, environmental conditions which may threaten human safety during such normal operations as diving or handling underwater drilling components, are often associated with rapid and localized phenomena. It is precisely those phenomena that are poorly measured and among the least predictable at present.

■ *PARAMETERIZATION AND MEASUREMENT* In describing ocean currents and water masses, basic physical parameters (speed and direction at a point, temperature, salinity, and density) have always been used in modern oceanography. These are entirely appropriate because they are fundamental to a dynamical understanding of currents, and are with the exception of density, directly measured in the ocean. Sensors have been developed to measure these parameters accurately, and the instruments and mooring techniques now used in offshore waters are adequate for most purposes.

Regulatory guidelines have dictated the use at drilling sites of 3 current meters distributed over the water column at 20 metre depth, mid-depth and near-bottom, usually 20 metres above the seabed. Much available data has come from moorings placed by offshore operators. In shallow areas (less than about 100

metres depth) 3 meters may give adequate vertical resolution of currents. In other areas, for example, along the Labrador Shelf, this scheme may not be satisfactory as the spacing between the meters may bracket core currents. Frequently, the description provided by these data of wind-driven currents and internal wave motions will be unsatisfactory for verifying predictive or interpretive models. Instrument deployments that are rationalized for dynamical oceanographic needs and take existing knowledge into account would lead to more useful data.

Instruments for detailed sampling of temperature and conductivity over depth are fully developed. They provide data on vertical density stratification essential to the prediction of wind-driven current extremes. Regulatory guidelines do not require collection of these data in conjunction with current meter deployments by industry. This is a serious shortcoming in these measurement programs since the absence of this data greatly limits interpretation and modelling.

■ *ANALYTICAL TECHNIQUES* The purpose of data analysis methods is to produce valid observations from instrumental records, and to separate motions into components that can be explained by various forcing mechanisms. Included in this latter category would be techniques to reveal those characteristics of the flow resulting from the interaction of waves (for example, tides) with the bathymetry. This is an area, tied to predictive models, of extremely active research in the oceanographic community. New procedures may be expected to come along regularly. There is no evidence to suggest, however, that present analytical methods are inadequate for data being collected in Canadian waters. Problems that exist have more to do with what data are collected, and where, than with the processing methods used on them.

■ *PREDICTIVE TECHNIQUES* Statistical methods for deriving extreme currents rely on having a long time-series of data. Ideally these are directly measured current data at a sufficient number of depths over the water column to define a velocity profile. Alternatively the current data could be hindcasted using empirical or deterministic models but there are limitations imposed by the quality of the wind data and by the models themselves. Rules for how long the time-series should be are lacking. This problem was examined in Davis Strait and it was found that errors in mean flow estimates would be about ±50 percent (±10 cm/s in 20 cm/s) for the 60-day records there. To improve this estimate significantly, about 3 years of continuous sampling would be required, but to achieve a ±10 percent error in the variance of the mean flow (important for estimating extremes) about 28 years of data would be needed.

These conditions are not fulfilled anywhere in eastern Canadian offshore waters. For only one area near Hibernia are there approximately three years of data. Even there, the data were collected at slightly different locations and while one expects the current differences to be small, differences must necessarily exist and have some influence on the accuracy of the predicted extremes. Moreover, the quality of instrumental measurements improved with time so that the data base has uneven accuracy.

■ *TIDAL CURRENTS* In general where there are 30 or more days of measured currents (hourly or more frequent sampling) tidal currents can be predicted by the harmonic method. Since most instrument deployments are longer than 30 days, estimates of maximum tidal currents that are likely to be adequate for rig evaluation and drilling operations can be made at the measurement locations. The accuracy of these predictions has yet to be established, however, and this limits confidence in the extremes.

A more serious problem arises when attempting to interpolate tidal currents between measurement sites. The bathymetry of the continental shelves and the coastal landforms produces strong spatial variations in tidal flows (for example, the area surrounding the mouth of Hudson Strait where tidal flows exceed five

knots). These effects can, in principle, be calculated using numerical hydrodynamic models given tidal water level variations along the model boundaries. Water level data at strategic deep-sea points are lacking over most of the study area. Exceptions include the extreme southern Scotian Shelf and the Grand Banks which are the focus of a recent data collection program.

It appears, then, that predictions of the magnitude and timing of maximum tidal currents at specific data locations can be made with reasonable accuracy. Because data points are clustered and spatial variations in tidal flows can be strong, interpolating site-specific data will be difficult. Deterministic models offer the potential to do this with reasonable accuracy; to date, however, this type of modelling has not been carried out and is constrained by lack of deep-sea water level data.

■ *WIND-DRIVEN CURRENTS* Wind-generated current extremes can be estimated using statistical models, or deterministic models forced by 50- or 100-year return wind histories. The first method requires that wind-driven currents be isolated from measurements, which is possible with present analytical techniques, and that the records span many years. This latter condition is not met by records in the study area.

Deterministic modelling driven by a time-series of local wind stress at the sea surface has the potential to provide good current predictions if the density stratification giving rise to the maximum response can be specified. In principle this is possible from the water property data archived by the Marine Environmental Data Service (MEDS) in Ottawa, although there may be some uncertainty introduced by the interpolation over depth. The second requirement is for field data to calibrate the models. These data are available over the Hibernia area, and the Scotian Shelf around Sable Island, where they have been measured with proper vector-averaging current meters. Elsewhere calibration data are few.

Empirical models based on the multiple coherence between wind and measured currents have the potential to greatly extend the measured data base by hindcasting currents from long-term wind records. These methods have not been applied to any location within the study area, but could be with a reasonable chance of success for Hibernia and some sites near Sable Island.

■ *RESIDUAL CURRENTS* Low-frequency background currents produced by density variations and seasonal changes in the surface wind stress distribution can only be predicted with confidence using statistical models based on time-series measurements; again, the requirement is for multiyear data sets, which are not available. Spatial variations are also large, depending on bathymetry and topography; thus interpolating between measurement sites is extremely difficult. Regional maps of geostrophic currents do exist for many areas of exploratory interest but these provide only the roughest guide as to where major currents may be located and their average flow speeds. These maps are of extremely limited accuracy in the engineering sense because they account for only a fraction of the net flow, and reveal nothing about the variability of the flow, over time scales of a few days to weeks.

Residual currents cannot be neglected in the derivation of extremes. Much of Canada's eastern offshore acreage is located in or near the major ocean currents along the coastline. These include the Baffin current in Lancaster Sound, Baffin Bay, and Davis Strait with maximum speeds ranging from 50 to 80 cm/s and the Labrador current along the Labrador Coast and the eastern edge of the Grand Banks with maximums ranging from 35 to 70 cm/s. In these areas the residual currents may exceed the tidal currents away from the coastal zone. Measurements will be required to estimate extremes of speed in these areas. Three-dimensional deterministic modelling incorporating density variations and changes in atmospheric forcing could, in principle, be applied, if sufficient data to initialize and run

these models were available. This, however, is not the case. Another problem is the cost of computing for models of this kind, together with uncertainties in the results due to assumptions made in their formulation. For these reasons, instrumental measurements, even for a short period, are to be considered more reliable than model predictions at this time.

■ *HIGH-FREQUENCY CURRENTS* Rapidly fluctuating currents, with periods of a few minutes to a few hours, are often disregarded when estimating extreme design currents. They are caused by such factors as internal waves near the surface or gravity currents along the sea bed, and can be sufficiently strong to disrupt drilling operations. Diving is particularly sensitive to rapid changes in current. Because large high-frequency currents are either rare or sporadic, their prediction is nearly impossible. This situation results from a poor understanding of their causes, for example, what triggers the formation of solitons in Davis Strait, and how do they propagate through the ocean. There are weaknesses with theoretical models in this area and a severe lack of oceanic observations.

Historical data have been collected (with the exception of the Davis Strait soliton work) with a view to ignoring high-frequency signals. Instruments were used with sampling intervals that were too long to resolve internal waves or they were placed too high above the sea bottom to record large currents there. It appears, however, that potentially dangerous current events are rather rare in the eastern Canadian offshore. Prediction will rely on measuring the phenomena that affect a given site, determining their frequency and periodicity if any, and using this information to anticipate the event and to schedule accordingly.

New data will be required to discover these phenomena (satellite imagery as well as conventional *in situ* measurements) and real-time data may well be needed to carry out exploratory operations. These techniques were successfully applied in Davis Strait for detecting solitons. Large amplitude internal waves have also been observed on the edge of the Scotian Shelf and tidal conditions along the Grand Banks may generate waves there. To date, though, no observations have been made of large internal waves over the Grand Banks.

■ *AVAILABILITY OF DATA* Current data have originated from three basic sources: government scientific research, industry baseline studies of a regional nature, and industry deployments in conjunction with well drilling. The last contribution is the largest. In view of the spatial distribution of data and the record durations at each location, it is apparent that no mulityear master plan has evolved that is oceanographically sensible. What is available now is a haphazard set of short-term records largely clustered around areas of active drilling or discovery. Systematic long-term measurements at locations that would delineate major currents and that would provide input data for predictive modelling, have not been undertaken. Thus it is possible to use some data for the derivation of extremes, but due to changes in instrument types and mooring locations, this exercise involves a great deal of judgement and patching together of records. Assumptions must be made about spatial variability with little hard evidence for guidance.

Regulatory guidelines for the industry have led to a policy of deploying current meters near well sites regardless of the time taken to complete a drilling program. There has been no impetus or necessity for measurements at fixed locations that would be of an essentially continuous nature. The guidelines produced data that were useful, perhaps, for answering questions about changes in proposed drilling programs on a well-by-well basis, but of much lower applicability for deriving long-term extremes. That approach was understandable in the early years of exploratory drilling but is less obviously correct in the light of recent discoveries and greatly expanded drilling in certain areas, for example, the northeast Grand Banks.

Any meaningful interpretation or modelling of ocean currents requires con-

current data on density variations over depth, and local and far-field winds. Local anemometer winds are generally available with industry data, but are seldom measured in government programs, even in terms of installing automatic shore-based weather stations. In none of the data base archives are meteorological data incorporated into the current meter records, although the data do exist and can be obtained by going to separate agencies such as the Atmospheric Environment Service.

Another serious shortcoming is the fact that conductivity and temperature depth profile data are not routinely collected with industry current-monitoring. As a result, detailed stratification data at the time and location of current measurements are generally lacking. This factor greatly constrains the interpretation of current observations, especially with respect to estimating wind-driven extremes. As with wind, stratification data that do exist are not identified and archived with current meter records. This means that dynamical studies of maximum currents must assemble data from several different sources, a time-consuming and often unsatisfactory task because of differences in identification, storage, and quality. As noted above, it seems as if no master plan or strategy oriented toward understanding currents, and the prediction of extremes of speed in response to natural forcing mechanisms, has been adopted for data collection and archiving. This argument can be extended also to wave data. The attention of offshore designers and operators is turning more and more to the joint occurrences of extremes of wind, waves, and currents. The separation in Canadian practice of how these data are measured, processed, and archived for climatological analysis makes this type of study difficult at present.

■ *CONCLUSIONS* From an oceanographic perspective there are many shortcomings in how data are collected and stored for later use, and these have a direct impact on how well design currents can be evaluated. Available data are not adequate to derive current extremes with the confidence that one normally associates with wind or wave criteria. Nevertheless, the existing data, their scientific interpretation, and industry studies have not revealed conditions that are beyond the drilling technology in use today, nor that appear to be limiting for rig design over most of the East Coast. A decade of offshore experience has also failed to turn up serious problems that could be attributed to ocean currents or extremes of temperature. The effects of waves and ice are much more serious.

One area of obvious concern is the mouth of Hudson Strait because currents there are very strong. Operational problems would be expected with spudding, BOP handling, riser design, and drill rig station-keeping. There are some data for the region collected in 1979, and industry personnel are aware of the conditions to be faced. Safe drilling in this area would demand more data than are presently available.

Also as exploratory drilling moves into deeper water along the edges of the continental shelf the role of currents may be expected to increase. One area of interest is the Flemish Pass where, because of the bathymetry, the outer branch of the Labrador current is focussed into a strong, persistent flow. Clearly the potential exists for large currents with a complex vertical structure, resulting from storm currents combining with the more permanent Labrador current. Here also more data, over many depths, are required.

The evaluation of rig performance and seakeeping ability demands that the vessel be analyzed for worst-case combined loads due to winds, waves, and currents. Traditional practice has involved adding up the individual extremes as derived largely from distinct and separate analyses of the various data types. Canadian practice has, seemingly, oriented data collection and archiving to respond to this approach. A major hurdle to examining combined events in nature is the separation of historical data in different archives, some missing data, and

uneveness in quality. More detailed, data-based studies into the response of the atmosphere and ocean together under extreme forcing is desirable. This approach would lead to more rational and realistic conditions for rig evaluation in any of the operating modes (transit, survival or drilling).

If we look ahead and anticipate more offshore drilling, followed by production, it would seem logical to reorient oceanographic data collection along more rational lines than are presently followed. Essential aspects include:

- Establishing predictive techniques for current extremes, and determining data requirements for them;
- Organizing long-term strategic monitoring stations that would provide meteorological, wave, current, and water property profile measurements;
- Standardizing instrumental and analytical techniques;
- Putting all data into one archive suitable for a dynamic analysis of winds and currents, in combination with wind waves.

SEABED INFORMATION

The Adequacy of Available Seabed Information as Input to Design Criteria and Operating Constraints for Eastern Canada Offshore Exploratory Drilling
Jacques, Whitford & Associates Limited
Halifax, Nova Scotia
January 1984

Although all drilling units involved in exploratory drilling off eastern Canada interact with the seabed through their anchoring systems and well connector devices, the interaction is most significant in the case of jack-up rigs which depend completely upon the seabed and underlying materials for support. Jack-up foundation systems fall into two categories: mat (three or more legs supported by a common foundation base) and footing (three or more footings or "spud cans") each supporting an individual leg. Mat-supported rigs have been developed to operate in areas with very soft seabed sediments while individual footing-supported rigs can more readily accommodate site variability. About 75 percent of jack-up units in use today, and all those employed to date in the study area, have footing-type foundations.

■ *FOUNDATION FAILURES* Foundation preloading has been widely used as a method of proof testing jack-up rigs. Ballast is added to force additional penetration of the footings to a level where the total bearing capacity exceeds, by an acceptable margin of safety, the maximum load anticipated by the designers. For most three-leg jack-ups, preloading is accomplished by pumping sea water selectively into a series of holding tanks, maintaining approximately equal loading on all legs during the process. The preload is generally held for a minimum time of two to four hours after all footing penetrations have ceased.

The most serious hazard associated with preload is "punch-through". In certain locations the subbottom soil profile includes a strong layer of soil overlying a weaker layer. If the bearing capacity of the hard layer is sufficient to allow the unit to elevate, but not sufficient to carry the preload, punch-through will occur as a spud can (usually only one) penetrates the hard layer and plunges rapidly until adequate resistance is encountered at some lower level. The magnitude of vertical movement and resulting tilt of the rig will depend on the depth of the weak layer of soil and the height of the rig's hull above water since the footing load will diminish once the hull submerges. There is little possibility for control once punch-through begins, since the applied load cannot immediately be removed or reduced although in some cases quick action (for example, jacking down the plunging leg and raising the others) can minimize damage.

There are several geologic factors that can produce the conditions for punch-through. Available seabed data are not sufficient to predict the occurrence of these conditions, but there are recognized methods of identifying their presence at a given location.

There are other circumstances related to seabed conditions that may lead to

jack-up foundation failure. There have been many instances of stability problems produced by scour on the sea floor. Scour undermines footings and reduces the depth of embedment, thus resulting in reduced bearing capacity. Depressions in the sea floor, whether naturally occurring such as pock marks, or caused by a previously installed rig, can create problems for spud cans positioned adjacent to the depression.

After a jack-up rig has reached location and raised its hull out of the water, its foundations are subjected to two types of loads, gravity and environmental. Gravity loads consist of the operational lightship weight and a variable load, and can usually be calculated within two percent accuracy by maintaining a careful inventory of equipment, materials, and supplies. Environmental loads include some combination of wind, wave, current, and structural icing and are considerably harder to calculate with any degree of accuracy. Estimates for environmental loading are based upon statistical data for each parameter specific to the site of operation.

During a storm, overturning moments caused by wave and wind forces may increase the vertical load on a footing by as much as 35 to 50 percent of the gravity load. The horizontal footing load during a storm may range from about one-tenth to one-third the magnitude of the total vertical footing load. There have been cases of excessive, uncontrolled penetration of one or more footings when storm loadings exceeded the maximum estimates established by the rig designers for preload testing.

Wave action, the most significant form of environmental loading, can produce about 55 to 65 percent of the total lateral loading with wind representing about 25 to 35 percent. Forces generated by the typical 1-knot design current amount to about 10 percent of lateral loading but in some places, like the Bay of Fundy where currents of as much as 4 knots occur, the resulting forces become much larger and hence more significant.

Jack-up foundation problems which may affect safety arise in two main circumstances: if the rig is unsuitable for the site, or if a procedural error takes place in moving the rig on or off location or during jacking operations. Accident reports suggest that the first of these is the most common cause of foundation failures. A rig that is "unsuitable" in this context could be one with insufficient leg length, or a footing area that is too small to avoid punching through a hard layer. In order to choose a suitable unit for a site, the operator must have advance knowledge of seabed conditions at the site and of how these conditions relate to the proposed unit's performance. Regional surficial seabed maps do not provide information in sufficient detail for this purpose and it is necessary to undertake site-specific and geotechnical surveys.

Some classical analytical procedures have been adapted to predict the bearing capacity of jack-up unit footings in different soil systems. Potential scour problems can be identified from boring data or geological evidence and solved by placing scour-resistent material around the edge of the foundation (traditionally sand bags, oyster shells or gravel), or by using an airlift waterjet system to achieve penetration of at least five metres below the sea floor prior to preloading.

Procedural errors such as insufficient preload, incorrect estimation of gravity or storm loads, excessive elevation of the hull prior to preloading, and improperly balanced leg loads when setting up or preparing for a storm are believed to have contributed to a number of foundation accidents. It therefore appears that better instrumentation and predictive techniques for estimating loads, and more specific attention to foundation problems in operating manuals are important in maintaining safety standards.

■ *ANCHORING SYSTEMS* The catenary anchoring systems in general use today by moored drilling units consist of chain or wire rope with sufficient length and weight

to remain tangent with the sea floor even under maximum line tension. The holding capacity is predicted from the empirical relationships between weight and seabed soil type, previous experience, and extrapolations from small-scale tests. The standard verification procedure for holding capacity, proof testing by short-term static pull or drag at relatively high velocity, ignores the effect of the cyclic load component present during storm conditions, and so may not provide a realistic measure. Proof testing of heavy anchors is also impractical and costly, and this method of verification could be supplemented by holding capacity predictions based on soil mechanics principles. Development work in this direction is underway at a number of institutions.

■ *WELL CONDUCTORS* Conductor pipes and casings are used primarily for well control during drilling and are more related to down-hole considerations than to seabed conditions. They do, however, interact with the seabed materials since it is from these materials that the conductor pipe and the upper portions of the conductor casing derive their support.

The loads which conductors are required to resist include gravity loads from self-weight and well-head equipment such as blowout preventors, and imposed loads from marine risers, waves, and currents. The loads are generally more severe in the case of floating drilling units where well-head equipment is located on the sea floor than for jack-ups where the equipment is located on the structure.

Lateral and flexural loads on the conductors are resisted by horizontal soil reaction stresses. Soil mechanics procedures developed for the analysis of laterally loaded piles can be used for analysis and design. The lateral resistance of the soil near the sea floor is significant to the analysis and the effects of scour and soil disturbance on this resistance during conductor installation have to be considered.

■ *CONCLUSIONS* Available information on the eastern Canada seabed offshore is considered to be useful as a guide to probable conditions but is not sufficient to permit evaluation of their potential effects on the safety of drilling operations. Such an evaluation would require detailed knowledge and an engineering assessment of both the geological features which may occur at the site and such geotechnical parameters as soil strength and density.

Geological studies on continental shelves are directed mainly towards identifying the depositional history and distribution of materials forming the shelf deposits. These studies, despite their usefulness in other areas, do not provide the data necessary for quantifying the risk associated with drilling operations. Geophysical surveys carried out with side scan sonar and acoustic profiling systems are an essential part of the investigation of potential drilling sites and are required by the Canada Oil and Gas Lands Administration (COGLA) regulations. These remote-sensing methods provide data from which information on seabed materials and formation must be inferred. Geotechnical investigations, which are not required by regulation, involve the actual sampling and testing of the seabed materials at a proposed site; physical properties can then be measured directly rather than inferred. Methods using gravity corers, geotechnical borings, and laboratory and *in situ* testing can determine with a high degree of accuracy the stratigraphy and engineering properties of the seabed material. The most useful data source on a specific site would be an integrated study of geophysical data and geotechnical borings. This combination allows geotechnical conditions to be correlated with acoustic profiles through the boring site, and thus provides information on the probable extent and thickness of soil layers as well as on their physical properties over a considerable distance. These combined studies are even more effective if they are tied into the regional geological framework.

Existing statutory regulations applicable to the overall eastern Canada offshore do not specifically require geotechnical investigations at proposed drill sites. They thus do not ensure that the information required to quantify the risk related

to seabed/structure interaction is obtained. Requiring site-specific geotechnical investigations would provide the data necessary to minimize the risks involved with offshore exploration activities.

Summary of Environment Seminar

Upon completion of draft reports on the physical environment (Ice, Wave Climatology, Forecasting, Climatology, Seabed, Oceanography) a seminar was held by the Royal Commission. Attending were authors of the studies plus a number of representatives of the Canadian Petroleum Association, Offshore Operators Division (CPA) member companies selected through consultation with the Environment Committee of CPA.

While the scope of studies addressed requirements for design as well as operations, the seminar was called to focus on the latter, reflecting the experience and role of CPA. Resource persons from Memorial University of Newfoundland, Bedford Institute of Oceanography, and the federal government (COGLA), along with members of the Royal Commission resulted in a total of 46 attendees. The seminar was organized into a number of topics corresponding to studies with each author making an initial summary presentation of their work followed by discussion. The final session ended with a round table where each participant presented concluding views.

Perhaps the most consistent theme that emerged during the discussions was the view of industry representatives that the reports presented for consideration did not contain enough input from the operational community and did not adequately distinguish, in the words of one participant, "what was scientifically desirable from what was operationally, technically, and physically feasible."

Although there was general agreement that more baseline data are needed in a number of environmental areas, concern was expressed that any new data collection programs be developed with industrial as well as scientific goals in mind. If the overall purpose of improving the existing systems is to improve safety conditions for offshore workers, then some attempt should be made to break the general recommendations of the reports down into specific instances where obtaining more or better data would lead directly to safer working conditions. General agreement was reached on the need for more real-time data dissemination, particularly in the area of ice, and on the desirability of improving the accuracy of weather forecasts. At the same time, though, it was recognized that inadequate data are often less problematic than poor understanding of user needs by the data originator, ineffective communication between the two, or an inability in terms of time or expertise for the user to interpret properly the data received. Improved training for those on board rigs who are responsible for manipulating environmental data, and automatic collection and transmission methods that minimize the time required of key personnel should result in better use of present data bases.

In the area of research and development, the priorities in terms of human safety were identified as the operation of safety and emergency equipment during harsh weather conditions, particularly icing, and improvements in ice detection techniques. Some concern was expressed about the need to distinguish between environmental data considerations related to exploratory drilling as distinct from those related to production.

Industry representatives encouraged the Royal Commission to incorporate the feedback obtained through the seminar into the study reports, and to seek more input from operational and regulatory groups wherever possible. They also suggested that the reports be amended to permit some focus on the present safety record of industry in order to provide a more balanced view of the risks involved in offshore work, and on the efforts that have already been made to assemble an industry-generated data base for the Hibernia site. Other participants cautioned against complacency and pointed out that despite the excellent safety record, the

situation on the Grand Banks was still largely untested and many of the ice-related parameters were as yet poorly understood.

It was felt by a number of industry representatives that Newfoundland Oceans Research and Development Corp. (NORDCO) had overdramatized the situation in its report on the adequacy of available ice information. The present operational safety record is based on a philosophy of ice avoidance and carried out through a controlled program of detection, tracking, and deflection where possible. This ice management strategy allows for the uncertainities of present environmental data bases. Despite their general conclusion that existing ice information was, in fact, adequate to protect human safety, industry-based participants did make several suggestions for improvement. They felt that there should be a regulatory requirement that everybody involved in the offshore submit their ice information in real time to one source, and that that information be collected, analyzed and sent back to the users. It was also suggested that detection capability be improved and that a government-sponsored ice detection program be initiated. Some discussion followed on who should be responsible for regional and site-specific ice detection; emphasis was placed on current cooperative industry programs in ice detection and management and on the research efforts being funded by industry through the Environmental Studies Revolving Funds (ESRF).

Representatives of several research agencies updated the seminar on ice-related developments, and pointed out specific areas of concern. It was maintained, for instance, that small pieces of ice moving at high velocities are difficult to detect, and do pose a threat to human safety. Industry spokesmen questioned this claim and again emphasized the present safety record, current industry-sponsored programs to develop more effective radar, and ongoing ESRF programs aimed at improving ice towing and handling techniques.

The Climatology report produced by the Atmospheric Environment Service was reviewed and those in attendance were brought up to date on recent developments in climatological research. Industry representatives suggested that the scientific data needs of marine climatology are much more demanding than the operational data needs for offshore safety, and that many of the areas cited for concern in the report, do not, in fact, pose operational problems. The point was also made that the report failed to acknowledge the extensive body of climatological data being collected by industry on an individual company or cooperative basis. Delegates from AES agreed with the need to place more emphasis on the user and pointed out that the main user requirement tended to be for 100-year or extreme events. For this particular application, the present data base offshore eastern Canada is, in their opinion, inadequate.

The Seabed report by Jacques, Whitford and Associates highlights those seabed conditions which may lead to jack-up accidents, particularly punch-through. It was established during discussion that conditions which could result in punch-through do exist on the Grand Banks, although no accidents of this type have occurred to date. Considerable debate followed on whether regulations should require site-specific geotechnical investigations, including borehole programs. The author maintained that seismic studies can only lead to inferences about geotechnical properties; it is, therefore, good engineering practice to use a borehole program to determine from actual evidence whether punch-through conditions exist before locating a jack-up rig on a specific site. Scour and anchor problems were then discussed and an industry spokesman concluded that the report did not qualify many of its more pessimistic statements, and that in view of

the present safety record of jack-ups, the available seabed information and the techniques in current use were, in fact, adequate.

The general conclusion of the Wave Climate study by Marine Environmental Data Service and W.F. Baird Associates is that the present data base is weak, particularly in the northern regions of the study area and that improvements in collection and forecasting techniques are desirable. Most of the discussion was devoted to clarifying technical points from the report. Industry again expressed some dissatisfaction with the lack of direct correlation between the report's recommendations and operational safety considerations and emphasized that accuracy was in many ways less important than clarifying user needs. The point was also made that while much of the data may be important to designers, the rigs operating off the East Coast of Canada are already in existence and more attention should have been paid to the capabilities of these units. The report's authors commented that there wasn't enough publicly available data to make a link between wave criteria and operational requirements.

The Oceanography report by Seaconsult was received favourably by industry, and general support was expressed for its conclusions that available oceanographic data were adequate as input into design criteria and operational safety offshore. Some discussion ensued on the archiving of data and the time lag involved in making it accessible, and support was expressed for standardized procedures. Industry representatives pointed out that many oceanographic data collection programs had been carried out by oil companies either individually or conjointly, and that these studies were not recognized in the report's review of available data sources.

The Weather Forecasting report was prepared by Seaconsult Ltd. Delegates from AES provided an update of verification procedures used by that organization and a COGLA spokesman added that they were presently undergoing a review of verification requirements for private forecasting firms. AES reported on preliminary results verifying forecast accuracy for the Grand Banks in winter, noting that AES forecasters predicted the correct Beaufort scale wind speed range only about 37 percent of the time for lead times of up to six hours. Industry representatives stressed the need for uncomplicated, standardized verification procedures, and questioned the necessity for "higher content" forecasts as recommended in the report. Seaconsult personnel explained that the concern expressed in the report regarding mesoscale phenomena related to overall improvements that were needed in forecast technology and not specifically to the offshore, where these phenomena do not last long enough to pose problems. It was agreed that an application of the report's findings to offshore operations would be useful, and the Royal Commission reported that Seaconsult would prepare a supplementary report, in consultation with rig and regulatory personnel, which would relate the findings of the first one directly to user needs.

3

DESIGN

DESIGN

MOBILE OFFSHORE DRILLING UNIT DESIGN EVOLUTION

(1) *An Essay on the Design of Mobile Offshore Drilling Units*
(2) *Report on Mobile Offshore Drilling Unit Design Evolution*
Earl & Wright Consulting Engineers
San Francisco, California, USA
May/June 1984

MODU design has evolved from the use of land-based drilling equipment on shallow water barges in the late 1940s to the present day when world-class drilling units are capable of operating for extended periods in water depths of 100 to 460 metres and under very extreme environmental conditions. The factors that governed the design of early MODUs still dictate the concepts and techniques being applied today; essentially a MODU must provide a stable, highly mobile platform for drilling in deep water offshore, under a prescribed set of operating conditions. To cope with new conditions, designers either modify existing designs until a limit of extrapolation is reached or develop alternative concepts. The principal mechanism for evolution of MODU designs has been the change in configuration brought about by increased functional requirements and environmental limits.

MODUs can be separated into two general groups, bottom-supported and floating. Bottom-supported units include submersibles and jack-ups, while drill ships, drill barges, and semisubmersible units make up the floating group. Floating MODUs maintain position at the drilling location either with catenary mooring or dynamic-positioning systems or some combination of both. In evolving the design of MODUs there were some overlaps between these broad groups, for example, a number of early semisubmersible designs were capable of operating as submersible units in very shallow water.

The first true offshore drilling units were inland drill barges which consisted of land rigs mounted on barges that operated in swampy areas with less than three metres of water. The drilling equipment was installed on a deck raised above the barge hull and supported by posts or piles. The barge was moved on location and submerged, leaving the drilling equipment above the waterline. The instability encountered during the process of submerging led to design refinements which produced the first true submersibles.

The first submersible was the Barnsdall-Hayward design *Breton Rig 20* built in 1949. This rig incorporated design features which provided increased stability while the barge was being submerged. Once the barge was on the bottom, its pontoons were flooded and sunk to minimize the effects of wave forces. Further refinements to this initial concept led to the introduction of the "bottle-type" submersible, the first of which was *Rig 46* now owned by Trans World Drilling Company. This unit, built in 1956, was capable of drilling in 21 metres of water. It featured large diameter columns that provided stability during towing as well as during the lowering procedure. The largest submersible rig, *Rig 54*, also owned by Trans World Drilling Company, was built in 1962 and operated in water depths up

to 53 metres, which proved to be the economic limit for the submersible type MODU.

Self-elevating or jack-up type drilling units were first developed in the mid-1950s, in response to the limitations of submersible rigs. Developed to provide a means of keeping the drilling platform above the wave crests for depths exceeding the capabilities of submersibles, jack-ups derived many of their features from earlier marine construction platforms which were floated to a particular site and raised above the water on steel piles or legs. Due to the limited capacity of the jacking devices employed on early jack-up units, some had as many as 10 or 12 legs. Advances in jack-up design reduced the number of legs, leading to the development of a triangular, barge-type hull with 3 tubular or lattice truss legs. Jack-ups were initially developed for shallow water sites in the Gulf of Mexico and the Middle East. These units operated in water depths of less than 30 metres and in areas where environmental conditions (with the exception of hurricanes) were relatively mild. With the movement of exploratory drilling operations into more severe climates, however, continued improvements in jacking equipment, leg-to-hull connections, and the legs themselves were necessitated. Excessive leg penetration into the seabed was also a problem encountered with early jack-up designs; this led to the development of spud cans to increase the leg's bearing area. The development of the mat-supported type jack-up was another solution to the penetration problem.

As drilling locations extended to more remote areas and increasing water depths, designers were forced to abandon the bottom support concept and turned to the development of floating drilling units. The initial designs involved the conversion of conventional ship-shaped vessels to carry a complete drilling system. Purpose-built drill ships appeared in the 1960s and although contemporary designs have increased stability by providing wider hulls, bilge keels, and roll suppression systems, drill ships are still limited in their operation by relatively poor motion response. With the exception of the introduction of dynamic-positioning systems which allow the vessel to "weathervane" with the prevailing wind and sea state and thus minimize motions, the basic design concept of the drill ship has not changed in a significant manner since its introduction.

From the experience gained in developing the submersible and recognizing the inherent limitations of ship-shaped drilling units, designers developed the semisubmersible concept. In general, semisubmersibles exhibited improved motion characteristics when compared with drill ships. Consequently, these units have evolved as the most common MODU used for operations in deep water and severe environments. Early semisubmersible designs had multiple lower hulls and stability columns, ranging from 4 or more lower hulls and up to 20 columns. Major buoyancy members were located below the water line because the effect of wave action is reduced with increased water depth thus improving the unit's motion characteristics. The early designs had inherent stability, strength, and maintenance problems due to the overall structural complexity. The desire to provide a simplified structural framing arrangement, increased transit speed, and mobility led to the development of the modern twin hull semisubmersible configuration.

■ *MODU DESIGN* The design of MODUs is an iterative and evolutionary process of incredible complexity. The constraints of operating performance and regulatory requirements coupled with economic, technical, and human factors force designers to seek an optimum engineering solution through the application of new and existing principles, materials, and technology. The extent to which the design process interacts with a unit's construction and subsequent operation varies considerably. In some cases, a designer may monitor the rig throughout its working life, while in other circumstances his involvement ceases before construction begins. Throughout the design process, professional judgement is exercised to establish

the MODU's level of safety, especially in those areas where analytical methods are questionable. The final product, a drilling unit optimized for a specific range of operating conditions, is typically the result of four stages: the development of a conceptual design; the preparation of a design basis; a preliminary design; and a final design.

The conceptual design stage involves developing and defining the MODU's capabilities and is a good starting point from which to develop a unit that satisfies the needs of a client or project. If a client is involved during the conceptual design phase, his requirements are an important consideration. Conceptual designs are, however, also prepared either on speculation or in anticipation of the development of a potential project.

To decide the size and capability of the MODU, basic operating parameters must be defined, including: anticipated geographic area of operation, environmental forces, motion limitations, required payload, mooring system and dynamic positioning system, transit requirements, crew size, and applicable regulations. Based on these parameters the conceptual design studies should result in sizing a unit within about ten percent of its final size. When the initial sizing has been completed, a gross expected lightship weight is developed using the designer's past experience with the weights of drilling equipment, ship's service equipment, and structural components. An analysis of the stability and motions of the conceptual design is performed and the results are compared with the characteristics of existing MODUs.

At the end of the conceptual design phase, a concise report of the findings is produced and the results are reviewed against the required parameters and discussed with the client, when one is involved. It is often possible to establish a cost estimate for the conceptual unit to help develop an operating day rate. If the proposed unit's configuration departs sharply from the norm, an "approval in concept" may be discussed with a classification society to forestall future problems.

Following the approval of the conceptual design, the designer integrates the operating parameters and criteria developed during that phase with more detailed design aspects to ensure that the final product will truly meet the needs of the client. Detailed operating requirements are developed including basic criteria for ship's service and drilling systems as well as structural aspects such as the required fatigue life. A decision regarding the classification society to be used and the country of registry is made, in order to allow the design to meet the appropriate requirements. In addition, the regulatory agencies governing the anticipated geographic areas of operation are identified so that the design incorporates a proper and economical approach to their various regulations. The design basis phase results in a formal design procedure document which also incorporates the technical approach for the structural, mechanical, electrical, and other design disciplines.

Once the conceptual design is complete and the design basis has been defined and accepted, the preliminary design phase begins. The basic arrangements of the deck are developed to confirm or modify the space allocations determined during the conceptual design phase. The structural framing scheme and weight estimates for the structure are developed using mathematical analysis in combination with past experience. Emphasis is placed on developing a simple, straightforward framing system with inherent redundancy in case of damage. Engineering drawings indicating the basic structural scheme and sizing are produced. Using the conceptual design configuration and sizing as a starting point, the designers' naval architect estimates the unit's lightship weight and vertical centre of gravity, and analyses the stability and compartmentation required. A mathematical analysis is performed to determine the motions of the unit; many iterations of the initial design and configuration may be made to optimize the motions.

When the foregoing steps have been completed, a drilling efficiency or "downtime" analysis may be required by the leasing client or the owner.

A great deal of the basic mechanical and electrical design is also performed during the preliminary design stage. The requirements for the bilge, ballast, and cooling water systems are determined and schematic drawings of the systems are made. To verify space requirements and allocation, basic layouts are done for the mechanical equipment, including the pump rooms. An initial power and electrical load analysis is performed to determine the required generator capacity and to produce a simple, one line power distribution drawing. An estimate of equipment weights is made for inclusion in the lightship weight estimate. Some consideration for model testing is often given at this stage, particularly where a new configuration, which differs significantly from other designs, is undertaken. Model basin and wind tunnel tests are used to verify motion response, wave passing, towing and propulsion requirements, and the effects of environmental forces. At this point, a decision is made as to the need or value of submitting the preliminary design package to regulatory agencies for "approval in principle". A submission of this nature can settle basic questions and clear the way for the final design.

In the final design stage a set of drawings and construction specifications are developed for approval by a classification society and applicable regulatory agencies. These drawings and specifications define the unit as it is to be built and form the basis for shipyard bids. The final design will incorporate detailed arrangements for the layout of the unit, a detailed structural design and analysis, the naval architectural analysis for stability and mooring, a detailed mechanical and electrical design, and a construction specification which defines the material, equipment, and workmanship required for the completed unit.

When the final design is submitted for classification/regulatory approval, many different groups within each society or agency review the plans of the unit. The approval process can therefore be quite lengthy and is very seldom complete before construction bids are requested. Therefore, during the construction period, the approval process goes on, not only of the construction documents, but also of design aspects. To minimize possible changes at the shipyard, particularly after steel is ordered, an effort is made during design to submit the job in segments to the agencies.

■ *DESIGN TRENDS* The design concepts for the three major types of MODUs employed in East Coast Canadian waters – jack-ups, drill ships, and semisubmersibles – have developed to a point where current and future trends are primarily directed toward refining individual systems, reducing cost, and improving speed of construction. Major developments have occurred in the areas of stability and watertight integrity, mooring and dynamic-positioning systems, ballast systems and marine service systems. Advances in the understanding of metal fatigue have led to changes in welding procedures for MODU fabrication. Improvements in the operational aspects of rigs working in harsh environments have also been attempted.

In most early MODU designs, stability considerations were limited to providing a sufficient metacentric height (GM) and waterplane area to resist the effects of 35 to 50 metre-per-second storm winds. Gradually other considerations were addressed and accidental flooding criteria were adopted to enable MODUs to survive damage resulting from collisions. Early designers had essentially no guidance on stability for MODUs, as the majority of the stability regulations were developed for conventional ship-shaped vessels. Stability was provided by following basic principles of naval architecture. For intact stability, the primary requirement was to maintain a positive GM at all drafts and to provide sufficient GM at operating draft to facilitate the drilling operation. For units with an off-centre drilling derrick, this could be a serious problem due to trim induced by large variable drilling loads on

the hook and derrick. Intact stability for semisubmersibles posed no particular problem once operational requirements were met. The same situation existed for jack-ups and drill ships, however, in these cases freeboard was an important factor influencing intact stability. The relatively high casualty record for jack-ups under tow can be attributed in part to a less seaworthy hull form with a small amount of freeboard and the very high position of the elevated legs which often causes synchronous roll with the seas.

The contemporary intact stability rules for MODUs are intended to ensure that a unit possesses sufficient righting energy to offset the overturning energy due to wind. All of the factors in these rules are attempts to account for dynamic effects by applying empirical analysis; although the rules have proven satisfactory, considerable research is under way to provide a more thorough understanding of environmental effects on intact stability.

To provide some measure of damage stability the early barge type MODUs had some internal watertight bulkheads or other subdivision, but in the majority of cases there were no explicit criteria defining the extent to which flooding would be tolerated. Typically designers allowed for one compartment to be flooded and applied some constraint either on freeboard or angle of inclination after flooding. The first formally published rules for MODU design issued in 1968 by the American Bureau of Shipping called for a one-compartment standard with positive freeboard after damage, including the static effect of a 50-knot wind. There was some confusion as to whether the standard applied to any one compartment or only compartments near the waterline. This was, however, clarified in the 1973 edition of the rules to cover single or multiple compartment damage only near the waterline.

The contemporary damage stability rules of classification societies either apply a one-compartment damage requirement or a more stringent one. The static effect of a 50-knot wind is included, but there is no allowance for waves and motions in terms of freeboard to downflooding openings. Many flooding casualties can be traced to wave entry through multiple openings above the static intact waterline. To allow for ballasting or other operational errors as well as inadvertent flooding, many designers feel that a one-compartment flooding standard without reference to the waterline is necessary.

The consideration given to a MODU's stability has progressed from the "rule-of-thumb" methods employed in early units to the highly regulated considerations which are in effect today. Although there is a continuing desire to adopt more rational intact stability criteria, there is no compelling argument that the existing rules are inadequate. There remains some question, however, regarding the applicability of existing rules for harsh environment areas.

A MODU's mooring or dynamic-positioning system must provide precise control of the vessel above the wellhead and produce sufficient resistance to hold the vessel on location under normal operating conditions. These considerations have led to the development of more complex systems than are usually employed for ships. Conventionally moored MODUs are presently limited to operations in water depths of approximately 460 metres. Beyond this limit, the weight of the mooring system components reduces the MODU's payload capacity. In addition, as water depth increases, the positioning capability of catenary mooring systems becomes less effective and the MODU cannot be maintained over the wellhead in rough seas.

Dynamic-positioning systems first evolved as part of thruster assisted conventional mooring systems. Control systems were developed to regulate both thrust and direction of the individual thrusters thus allowing full dynamic-positioning systems to become a feasible option. While contemporary dynamic-positioning systems make it possible to dispense with anchors as a backup, this is not economical in moderate water depths and not possible in very shallow water. In

eastern Canadian waters MODUs equipped with dynamic-positioning systems also use conventional mooring systems.

Recent developments in dynamic-positioning systems include improvements to position sensing and control equipment and advances in thruster design. Conventional mooring systems have improved through the use of high strength chain, emergency release systems, automatic tension monitoring and load sharing, and chain chaser lines. In addition, onboard computers are making it possible for personnel to carry out evaluations of vessel motions and anchor line dynamics to optimize anchor patterns, predict tensions, and analyze the effect of operational changes.

Early MODUs, especially jack-ups, did not have dedicated ballast systems until submersibles and semisubmersibles were developed. At best, most units had some type of bilge pump or draining arrangement as required by classification rules developed for ships. A new set of ballast system requirements were developed for semisubmersibles. In early semisubmersibles, ballasting was accomplished by gravity flooding into the pontoon tanks, while deballasting required pumping the bottom ballast tank empty. If other tanks were to be deballasted or ballasted they were connected to a central tank which communicated with a bottom ballast tank. Although operators could control such systems safely, there was a general desire to have somewhat more positive and direct control of each ballast tank. This need resulted in the centralized ballast manifold which allowed valves to be more accessible and each tank to be controlled individually. In systems with common manifolds, block valves have been introduced to divide the manifold to prevent the accidental transfer of ballast between tanks at the extreme ends of the pontoons. In general, ballast system arrangements have evolved towards more centralized and accessible equipment.

For jack-up units several approaches are used to trim the unit while afloat. When the hull is jacked out of the water a short distance, jack-ups must use a preload system to transfer sufficient weight to the legs to ensure proper seabed penetration. After the required penetration has been achieved the tanks are deballasted and no further ballasting is required. For "mat type" jack-ups, the mat may be filled with water to provide the necessary bearing pressure when on location. Prior to a long move, the mat is sometimes deballasted using air pressure.

Semisubmersible ballast systems have gradually increased in complexity. To sustain more severe damage conditions, the number of ballast tanks has increased. Additional pumps and pump rooms have been added in some cases to provide for safe operation at large angles of inclination and to provide for some level of redundancy in the system. As these systems become more complex, the trend will to be toward more sophisticated control systems. If safety is to be increased, or at least maintained, design for reliability and simplicity in these systems must be encouraged.

Classification rules, in this area, apply mainly to hardware requirements for ballast system components and to bilge systems. A need has been recognized for the development of operating criteria for ballast systems, and considerable effort is being focussed on this area by both regulators and owners.

As MODUs have evolved, their marine service systems have become increasingly complex. System requirements for cooling, fuel, compressed air and liquid, and dry mud as well as generator capacity have all increased significantly. Advances in computer technology have permitted an increase in the use of remote control and monitoring systems. The most significant design trend has been the attention placed on system redundancy and the use of systems during emergencies.

Exploratory drilling in areas exhibiting low temperatures and the presence of ice and icebergs has led to the incorporation of special design features. Many con-

temporary world-class drilling units, particularly those intended for cold-weather operation, incorporate heat traced piping and substantially enclosed working areas, including the drill floor. Formalized operating procedures have been developed for dealing with ice and snow loads, iceberg and pack ice contingencies, and the parting of anchor chains in emergencies. The most recent designs for world-class MODUs operating in arctic environments incorporate advances in materials technology, including the use of high tensile steel developed for use in cold temperatures.

At present, classification society rules address only limited ice strengthening of MODUs. The extent of this protection is confined to waterline areas at normal transit drafts and the strengthening is intended only to protect the hull from broken ice during transit in mostly open water. Very few MODUs have incorporated ice protection beyond basic classification society requirements, although several ice-strengthened semisubmersibles have been built for operation in areas with partial ice cover.

CONTINUITY FROM DESIGN TO OPERATION

Information Flow Report
Noble, Denton & Associates, Inc.
Houston, Texas, USA
December 1984

Each party involved in the design, construction, and operation of a MODU has basic responsibilities for the unit's safety. The owner is responsible for the safe and efficient operation of the MODU and is therefore responsible for ensuring that the unit has been designed and built for the environment in which it is intended to operate, that it is maintained adequately and that it meets the regulatory requirements for the area of operation. The designer is responsible for designing the unit to operate safely under specified environmental criteria, payload capacities, drilling capabilities, and operational limitations. The design must also satisfy the necessary classification rules and regulatory requirements. The builder is responsible for constructing the unit in accordance with the contract specifications, classification rules, regulatory requirements, and the specifications and drawings provided by the designer. The operator is responsible for contracting a unit that is capable of withstanding the environmental conditions within an acceptable risk level, and for ensuring that the unit meets all applicable regulations. The operator is also responsible for drilling operations including blowout and oil spill prevention measures.

A classification society performs an independent third party assessment of the MODU design, construction, and maintenance during operations for compliance with its rules to the extent that the unit is designed, built, and maintained in class. To a certain extent their design assessment will be on the basis of criteria specified by the designer and accepted by the owner. The roles of coastal state agencies and regulatory bodies are varied and requirements differ from jurisdiction to jurisdiction. Where government agencies have assumed a role in regulating the safety of MODUs, the operator is required to demonstrate that the unit is capable of operating safely. The regulatory body may also regulate safety equipment requirements and may require certain levels of crew qualifications and training. In some cases a marine surveyor may be employed by the owner or operator in order to meet the requirements of insurance underwriters. The marine surveyor's responsibility is to provide an independent assessment of the risks involved in moving and operating the unit.

A closer review of each party's role during the design, construction, and operation of a MODU is, however, required to highlight possible information flow failures. The roles of the various parties can never be exactly defined as they vary for each MODU project and are dependent on the perception of each individual group concerning their roles and responsibilities.

■ *THE OWNER* When a company decides to have a MODU constructed they will investigate the designs or design concepts which are available and capable of

meeting the requirements for an area of operation. If suitable designs or concepts are not available, they may either engage a designer to develop or modify a unit or engage their in-house design group to do so.

A combination of requirements must be met to ensure that the unit will be suitable. The environmental conditions must be established for the area of operations, particularly the wind, wave, and current forces during a storm with a 50- or 100-year recurrence period. The effect of environmental conditions on the design is considerable. The determination of maximum environmental conditions is not, however, an exact science and different consultants may provide data with a great deal of variance for the same area. Also, the estimated environmental extremes tend to increase as an operating area matures and a larger meteorological data base becomes available. These data, though sometimes of questionable accuracy, constitute one of the most important considerations during the design process and will often be the basis on which a design is accepted or rejected.

Classification societies approve designs for the environmental conditions specified by the designer; they do not judge if these conditions are acceptable for the intended area of operation. The owner, therefore, may have to assume additional responsibilities and establish more realistic operating, transit, and survival limitations for the area in question. Classification societies offer many optional coverages which must be specified by the owner in the construction contract. The selection of the classification society is often based on economic considerations; if the owner wants a different society than the one specified by the designer and/or builder, the contract price may be increased to cover the estimated costs for compliance. In reality the owner is not completely free to choose the society unless he specifies it very early in the design stage, or is willing to pay an additional charge to change. The owner will also select the home port of the unit and thus its country of registry; this in turn will determine which government regulations will be met. If the unit is to operate in areas such as the North Sea and offshore Canada, its classification and other certification is often not sufficient, since governments require an independent review of the design for compliance with their regulations. It is extremely important for the owner to specify the area of operation at an early stage of design to avoid the high cost of modifications.

It is common practice for the owner to supply most of the drilling equipment for the unit and often to supply mooring equipment, safety equipment, and general service equipment as well. If this is the case, the owner must work closely with the designer and the builder to ensure that all equipment information is provided in a timely fashion and that the equipment complies with applicable regulations. The owner, in effect, shoulders a certain amount of responsibility during the design. It is acknowledged that some designers have limited experience in drilling and marine operations; consequently the quality of the design may depend, to a large extent, on input provided by the owner. The owner must follow the design process very closely, using all his available knowledge and experience to ensure that operational assumptions are realistic. If the owner has knowledgeable and experienced staff working with the designer and builder, many gaps left by the design, classification, and certification processes can be eliminated. The fact that many designs are sold and constructed before an owner has been established may limit or eliminate the owner's involvement at this stage.

To minimize changes during construction it is in the builder's interest to limit the flow of information to the owner. This may be done by proclaiming most drawings to be of a proprietary nature and restricting the owner's access. The contractual obligations of the designer and builder are considered to be met when the classification society and regulatory agencies approve and certify the unit. However, the unit's classification may not cover all aspects of the design and consequently there may be major items not surveyed or tested adequately. Although the

owner's representatives will inspect the construction of the unit in parallel with a classification society's surveyors, in the case of disagreement regarding the quality of construction, the opinion of the classification surveyor will normally prevail.

Operating manuals generally do not become available until either late in the construction phase or at the actual delivery, thus limiting the owner's capability to familiarize himself with the unit's operations and making it almost impossible for the owner to instigate changes if procedures are found to be impractical. In many cases, operating manuals are inadequate and leave unanswered many questions that will occur during operation. The operating restrictions in the manual may be unnecessarily limiting and the owner may soon determine that the restrictions must be partially or wholly ignored. The owner will be fully responsible for all his actions beyond the manual's limitations, and the experience, knowledge, and judgement of his key personnel will determine if this will endanger the unit and its crew. Owners may decide to rewrite portions of the manual or expand it to cover operations that are not sufficiently addressed. If an owner decides to do this, he may be required to resubmit the manual for approval to the authorities that approved it originally. Whether this is actually done and whether all government authorities have procedures to deal with proposed changes, is not known.

■ *THE DESIGNER* A designer's role can vary from project to project and is contingent upon contractual relationships with an owner and his own view of his function. In cases where a designer is fully independent, criteria including the unit's operating environment will be defined. Then a suitable design is developed and marketed to prospective clients. Most jack-ups have been, and still are, designed by independent designers. In other circumstances, a designer may be instructed to develop or adapt a concept in close cooperation with the owner. It is obvious that in the first case the possibilities of information gaps are greatest, especially between designer and eventual owner.

To be successful, a designer must develop a commercially competitive design. This means that his efforts are directed towards developing a design that is cheaper to build than similar designs meeting the same criteria. Consequently, a designer will often try to minimize all systems and equipment that are a significant part of the unit's construction costs. To achieve this, a designer may employ the latest and most complex methods of analysis to show that environmental loads can be reduced and that the resulting lighter structures are capable of withstanding these reduced loads. It is possible that in some of these more efficient designs, the level of built-in structural redundancy is reduced and operational restrictions are imposed. Ideally, a designer should find a balance between commercial pressures and the safe and effective operation of the unit.

The extent to which a design is completed before sale is largely dependent on the designer's financial support, his commitment to the concept, and MODU market conditions. Several years ago when a building slot for a MODU was hard to find, many designs were sold before approval was obtained from a classification society. As the rig building market is currently depressed, potential owners require proof of adequate design development before contract negotiations occur. Consequently, the extent to which information is exchanged between designers and classification societies, regulatory bodies, and marine surveyors in the early design stages can vary considerably.

If a design has not been fully developed at the time of sale, the designer and builder tend to provide a limited amount of detail in the contract specifications. The favoured method is to describe the design criteria in rather general terms, and then make as much as possible subject to classification and regulatory approval, thus giving the owner little control over the design process.

Although classification rules and regulatory requirements may not have been intended to be a strict design and building code, they will, in effect, become one

unless the owner specifies in the contract adequate control of the design process. The minimum requirements in the classification rules and regulatory requirements may become the unit's maximum capabilities, while the poorly defined areas in those rules and regulations may become the unit's weaknesses. This process, however, is dependent on market conditions, and on the owner's experience, engineering capabilities, and negotiating skills when the contract specifications are established.

Apart from commercial and technical considerations, the delivery time for a MODU is important, since the unit may have to be built for a specific drilling contract. In many cases, the designer may have to issue unapproved drawings to the builder so that the planning and the ordering of materials may begin. Changes required during or after construction are costly.

The designer and builder will often approve amendments required by classification societies or regulatory bodies. These pressures may lead to a more literal interpretation of the contract, the specifications, and the contract drawings by the designer and builder in an effort to limit their responsibilities, while the owner will try to support a more liberal interpretation to receive a unit with minimal limitations.

Short delivery schedules can affect the orderly development and evaluation of a design. To expedite construction, the designer and builder may try to limit the owner's involvement in the approval process. The obvious method to reduce the pressures imposed by delivery time is to use or modify an existing design for the project. A considerable design effort may still be required because many designs must be adapted to suit a specific owner's requirements. In almost every case, all information must be submitted to classification and regulatory bodies for each MODU. Only in the case of genuine sister rigs being built at the same yard is the information submitted for one unit considered to be applicable for the others also.

As much of the design work may still be in progress during construction, most designers provide continuous support to the builder. A designer may either make all detailed workshop drawings, or be responsible for approved design drawings while the builder develops workshop drawings. The contract between the designer and builder may specify that the builder must either submit drawings to the designer for review or inform the designer of any significant changes. Changes may have to be discussed, the effect of different tolerances evaluated, and the effect of equipment and material substitution determined. Late information from the owner concerning owner-furnished equipment may delay the design of various systems and their submission for the approval of classification societies and regulatory authorities.

Unless the designer is part of the owner's organization, it is unlikely that he will receive any significant feedback concerning the unit's operational performance. To develop designs with improved operating characteristics, many designers would like to be more involved in the operation of their designs and rigs.

■ *THE BUILDER* The delineation of responsibilities between the builder and the designer is often hard to establish accurately. Where the builder obtains a licence from an independent designer to construct a certain design, he generally receives approved design drawings, examples of schedules, specifications, procedures, and available information from other units of identical design. Certain independent designers provide detailed information while others may provide general drawings and specifications that may not adequately address interferences between structures, systems, and equipment. The quality of the design information to be provided is hard to specify in contracts between a designer and a builder. In some cases, however, the design group is part of the builder's organization and the exchange of information will be less problematic. It is certainly in the builder's interest to investigate the quality of information and support that the independent

designer can and will provide before committing to build. Many costly changes have been made in designs during the early phases of construction. Due to the designer's often limited financial resources, the builder is often forced to absorb any extra costs.

When evaluating a design, a builder considers the quality of his own engineering/design group and construction capabilities. Many designs require construction tolerances, welding qualifications, material processing, and erection procedures that only an experienced builder can provide. It is not uncommon that certain designs require tolerances and procedures that conventional shipyards may not be able to provide.

The builder will generally be responsible for detailing the design, translating imperial measurements into metric and finding equivalent materials. The builder may then need to obtain approval from a classification society for these more detailed drawings, specifications, and procedures. It would be prudent in all cases to have the designer review detailed drawings prior to fabrication. This is seldom done, due to schedule, economic, and manpower limitations. Without a designer's involvement, a builder and a classification society's surveyor may not be fully aware of the importance of specific design details.

The builder clearly carries the major responsibility during the construction phase but relies on the designer's input to ensure successful performance. If large quantities of owner-furnished equipment are involved, the builder depends on the owner's information and support. Due to tight delivery schedules and extensive construction preparations, it is in the builder's interest to minimize last minute changes. Since meeting classification and regulation review has priority, the design and drawing review by the owner will be minimized. Although the builder's and owner's representative may realize that some changes will significantly enhance the MODU, they may never be implemented due to their effect on price and delivery time.

The builder will normally assign construction quality to a separate in-house quality control department. Although most builders have excellent quality control departments, some yards are limited in their ability to implement quality control standards. Although the builder will be responsible for the tests and trials required for the acceptance of the rig, many drilling system tests require the owner's involvement. Some necessary testing may not take place at all since it is not a classification requirement and was not specifically itemized in the construction contract.

As part of the acceptance process the builder is often responsible for producing as-built drawings, final equipment and systems' manuals, and various certificates required by the contract. Some designers enforce a very strict policy regarding the proprietary nature of their designs and do not provide the owner with certain structural drawings, despite the fact that various regulations require that a full set of drawings be on board the unit at all times.

As is the case with the designer, the builder may not get any significant feedback from the owner unless they have a close relationship or significant problems evolve. The builder's involvement may be limited to warranty claims, assistance with the MODU's mobilization and the supply of spare parts for the first years of operation.

■ *THE OPERATOR* The operator's direct involvement in the design phase is limited unless the unit is being designed for a specific drilling program. In such cases the operator's requirements are provided to the designer through the owner. For frontier areas where no proven MODU concepts exist, many operators become involved in the development of designs by commissioning conceptual design studies or by actively supporting owners with design development. Therefore, an operator may carry a certain responsibility for the overall quality of a MODU design.

The operator is responsible for specifying the environmental conditions under which the MODU must operate, and must make certain that a contracted unit can meet these criteria. The survival criteria may be obtained from independent sources or may be specified by regulatory agencies. If the survival criteria are not directly comparable with the unit's design criteria, the operator may have to obtain independent studies that prove the unit is capable of surviving the maximum environmental conditions. In some instances operators require full safety audits and extensive non-destructive testing programs.

Since most MODU operating manuals address only the marine aspect of the survival preparations, the operator should be responsible for ensuring that the procedures for shutting down the drilling operation interface with marine survival preparations. Many of these procedures may be developed in close cooperation with the owner and must be well understood by both parties. This requires that the operator's onboard representative has a good understanding of both the marine and environmental factors and the unit's design limitations.

■ *THE CLASSIFICATION SOCIETY* During the design phase the classification society performs an independent evaluation of the MODU design which covers structural design, stability, critical systems, and any additional equipment or systems that the owner may wish to be classed under the society's rules. The limits of a classification society's involvement are not always understood by the owner. The unit's structural evaluation is either passed strictly on criteria specified in the construction contract or on the basis of criteria specified in the society's rules. Design approval does not mean that the unit is capable of operating in every geographic location for which it is approved.

All classification societies carry out independent analyses of a MODU's stability. The structural design review is approached somewhat differently by different societies. For example, one society will review the designer's calculations and the assumptions used in the calculations, whereas another will perform a fully independent analysis using their own assumptions, based on the service limitations specified by the designer.

In recent years, classification societies have extended their involvement in MODU evaluation through memoranda of understanding with several national and international regulatory agencies. In such cases, the society will review the design for such certification concurrently with their review for classification. They will then extend their review as required by the regulations and perform any additional analyses required. The operating manual may then be reviewed by the classification society for compliance with the applicable regulations.

The classification society's surveyors will be at the builder's yard to ensure that the MODU is built in accordance with their rules and in accordance with the approved drawings. It is seldom possible for the limited number of surveyors to monitor all phases of the construction on a continuous basis. Their effectiveness will therefore depend on the builder's quality control department and the surveyor's relationship with that department. Many owners have their own quality control team at the builder's yard. Their effectiveness may, however, be limited unless the construction contract clearly specifies that their approval is also required. During construction, there will normally be regular contact between the owner's representative and the surveyors even though no direct contractual relationship exists between the owner and the classification society.

■ *REGULATORY AGENCIES* Since many coastal states require certification of MODUs before they are allowed to operate, MODU design is affected significantly by government regulations. If such regulations are close to the accepted norm for MODU design, there will be few changes required. If, however, the regulations are more stringent, the design may have to be completely modified or costly changes made to existing units. Since government regulations are applicable to specific

geographic areas, two design standards may develop since not every owner is willing to pay the price of complying with higher standards. Designers have no practical problems with most regulations, provided that they are clearly defined and are not subject to regular changes or personal interpretations by inspectors. Unfortunately, this is not always the case and since many construction contracts will simply specify that the designer and builder are fully responsible for compliance with certain regulations they may, in effect, take on a responsiblity that is not clearly defined.

After a unit has received the necessary certification, regular inspections are carried out by the coastal state to check the unit's compliance. Inspections may be concentrated on the safety aspects of the unit such as its stability, lifesaving system, firefighting system, and may include its blowout prevention and pollution control systems.

■ *THE MARINE SURVEYOR* The insurance industry has provided MODU operation insurance since the inception of mobile drilling operations in the United States. As the industry developed internationally, insurance coverage for international ocean towages was also offered. As a condition of the insurance, such marine ventures are carried out subject to the recommendations and approval of a recognized independent marine surveyor or consultant.

During the design phase, the marine surveyor's role is rather limited and entirely at the owner's, designer's, and builder's discretion; however, a well-known independent marine surveyor's recommendations for ocean and field tows have often been included in construction contracts. Owners have requested that the same marine surveyors carry out feasibility studies at the design stage to ensure that the unit can operate and move safely in the intended area of operation. Designers have also employed similar studies to show potential owners that the marine aspects of the design have been considered, and that the marine surveyor endorses the unit's capabilities. During construction the marine surveyor may be employed by the owner to evaluate design changes and to assist in preparing for the unit's first ocean tow.

Prior to beginning offshore operations, the marine surveyor may carry out feasibility studies if the conditions in the area of operations are not directly comparable with the unit's design criteria. These studies may be carried out on behalf of the owner or the operator. The surveyor may also carry out studies for the long distance transport or ocean tow of the unit. The surveyor may then inspect preparation for transit, attend load outs and offloadings, and provide a certificate of approval. The surveyor may also be on board during transit to ascertain that the feasibility study recommendations are followed.

Most marine surveyors also become involved in damage evaluation and in handling damage claims. As a result, their organizations have gained considerable experience with MODU marine problems. The marine surveyor's effectiveness is largely dependent on the industry's view of his role, his review and approval policies, and the knowledge and experience of his staff.

■ *GAPS IN INFORMATION FLOW* The various parties involved in the design, construction, and operation of MODUs participate in a complex interaction that is dependent on the qualifications of those parties, their understanding of the information provided, their own views of their roles, their willingness to collaborate and, to a certain extent, MODU market conditions.

Some potential concerns regarding the continuity of information flow have been identified. The extent of the basic classification design review and construction survey may be too limited. Obviously, the regulatory agencies can influence the extent of this coverage and in fact are beginning to do so. Construction contracts and specifications often leave large gaps in the description of the unit's capabilities and characteristics, and errors have been made in the translation of

the design information into detailed construction information. Once the unit is constructed and in operation, the record of its performance could be used as input to improve future design decisions. There is, however, a lack of any significant feedback to the designer and builder concerning design flaws discovered during operations, and no defined forum for the distribution of important information learned from casualties.

The potential for significant information flow gaps and problems in the interaction between parties involved certainly does exist, and can result in design flaws and increased risk levels. To what extent these gaps and problems result in serious hazards will depend largely on the commitment and knowledge of the parties involved. If their commitment, experience, and knowledge is of a high order, the MODU will likely be a safe and efficient unit.

Even if all precautions are taken, all regulations complied with, and all personnel well qualified, the possibilities of serious accidents can never be completely eliminated. MODU design is not an exact science and human judgement and human error will always remain a contributing factor to accidents. There is no doubt that the information flow process between the various parties involved can, in many cases, be improved.

JACK-UP RIG DESIGN

Jack-ups with Reference to the East Coast of Canada
Noble, Denton & Associates, Inc.
Houston, Texas, USA
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Self-elevating mobile drilling units (jack-ups) were first used for offshore oil exploration in the early 1950s, primarily in the Gulf of Mexico. The jack-up rig consists of a barge-hulled structure and a number of tubular or open lattice-type legs equipped with a jacking system which enables the barge to be lifted from the water to a sufficient height to provide wave clearance. To work in the shallow water around the U.S. Gulf Coast, early jack-up rigs were typically designed for 7- to 10-metre waves and 70-knot winds.

Even though the Gulf Coast is subjected to hurricanes which exceed these design values, the rigs' close proximity to shore provides sufficient working time to evacuate crews and sometimes even to bring the rigs into sheltered waters. Consequently, despite the loss of several rigs, the loss of life was small. This reliance on evacuation as a method of dealing with extreme environmental conditions has continued, and the jack-up rigs operating in the Gulf of Mexico today are often built to withstand only a 10-year return period hurricane. New designs of cantilevered units capable of withstanding a 50- or 100-year storm have been developed because jack-ups often work over fixed platforms which are designed to withstand a 100-year return period hurricane. The collapse of the jack-up under such environmental conditions could mean the collapse of the fixed platform and the production facility.

In more hostile areas of the world, such as the North Sea, Alaska, Australia, and offshore eastern Canada, storms are generally more frequent and storm warnings allow insufficient time for evacuation. Consequently, jack-ups operating in these areas need to be built to a more stringent 50- or 100-year storm level.

The level of risk involved in operating a jack-up at a particular location will vary subject to the local wind, wave, current, and soil conditions. Drilling contractors and operators may wish to work to different risk levels, depending on several factors such as previous knowledge of the site, the length of time the unit will be on location, and the consequences of structural damage. In certain areas, government authorities may dictate the risk level.

■ *CLASSIFICATION AND CERTIFICATION* Jack-up rigs are normally designed and built according to rules specified by a classification society. The classification society will approve a design for the storm criteria specified by the designer, survey the construction, and make regular surveys during the life of the unit to ensure the rig maintains its class. The classification society will normally not determine whether the design criteria are adequate for certain areas of operation, unless it is acting on behalf of the government authority whose certification must also be

obtained and, even then, will only do so if this authority specifies certain criteria or storm return periods.

In many cases, insurance underwriters require a separate certificate of approval to be obtained from a Warranty Survey House. The warranty surveyor ensures that the unit will stand up at the specific location and can be towed safely between locations whether the rig has its certificates or not. To assure the underwriters that the rig is adequate, it is necessary to obtain site specific meteorological and seabed data, check this against the design specification and generally make sure the unit can operate at the location with a sufficient margin of safety. It should be kept in mind that a jack-up rig's primary function is to operate in an elevated mode with the platform above all wave action. In a floating condition, with the legs sticking high up in the air, there will be sufficient seaworthiness for the intended purpose of moving the unit; however, no great seaworthiness should be expected from a jack-up rig afloat without extensive preparations. Most jack-up casualties happen when the rig is in transit, moving between locations or under tow. Some 70 percent of all accidents may be directly attributable to the marine environment and not to the drilling operation. Because of this, and because many rigs' crews are not mariners, it is often a requirement of the underwriter that a marine surveyor be in attendance during jacking-down, towing, jacking-up, and preloading.

■ *METEOROLOGICAL DATA* Jack-up rigs are designed to withstand the stresses associated with the maximum environmental conditions which can be expected to occur in a given period of time. Several different methods are used by meteorologists and oceanographers to predict extreme storm wave heights, wind speeds, and currents. For many areas, the lack of adequate historical data reduces the level of confidence which can be given to these estimates. Even in areas like the Gulf of Mexico, the variation in expert opinion is significant for particular water depths. Since the forces are approximately proportional to the square of the wind speed, current, and amplitude of the wave, these differences are quite significant. Once "generalized data" have been determined, it may be necessary to obtain a detailed "spot location report" that accounts for local variations, particularly if the unit is working near its survival capability. It is important that the appropriate regulatory authority, using the best available data, establish a set of maps showing the contours of extremes for the area under consideration.

The utilization of jack-ups in areas subject to sea ice, icebergs, and ice accretion requires special consideration because jack-up rigs built to date would not be able to withstand the force of an iceberg impact. It is necessary, therefore, to consider the weather conditions for the unit to jack down and get out of the way of an approaching iceberg. A period must be available where wave heights do not exceed approximately 1.5 metres, although some jack-ups are capable of jacking operations in waves up to 3 metres. Some areas offshore eastern Canada are subject to icing conditions from freezing rain, sea spray, and snow fall. Accumulated ice and snow add to the weight of the rig, in addition to causing operational problems. Ice loading on the helideck of one jack-up unit was a contributing cause to losing the helideck while under tow. Designing critical systems and components to ensure reliable operation in cold climates is essential for units that work offshore eastern Canada.

■ *LOCATION DATA* It is prudent to obtain full knowledge of the sea floor and shallow subseabed conditions prior to the emplacement of any bottom-supported unit. The operator should make a firm designation of the proposed location prior to the surveys and should not make last-minute changes to the location once the survey has been completed. Some casualties have been caused by a last minute change in location to one "close by" for which data had not been developed and which turned out to be significantly different. High quality navigational equipment

is necessary to ensure that the jack-up is placed exactly on the location that was surveyed.

A number of methods are used to survey the proposed site. A close grid bathymetric survey must be performed, typically covering a square area having sides of one kilometre centred on the location. In addition, a diver survey is performed over an area of at least 30 metres beyond the extreme parameter of the footings in order to ensure the absence of wrecks or other submarine hazards. In the event that the area cannot be surveyed by divers, it should be effectively dragged by a line suspended between two towing vessels or surveyed using side-scan sonar.

To ascertain the underlying lithology of the location, a high resolution seismic survey should be carried out to a depth of at least 60 metres, encompassing the same area as the bathymetric survey. Such high resolution acoustic profiling can alert operators to the presence of shallow gas, which constitutes a significant safety hazard during drilling. This data can also provide useful, although indirect, information on foundation conditions by providing a basis for extrapolating available soil bearing data, by identifying three dimensional sedimentary features over a large area which cannot be defined by conventional geotechnical borings and by identifying faults and changes in lithology associated with crusts and gas pockets. A coring, or *in-situ* pressuremeter test, is desirable to ascertain the soil type and shear values at various levels below seabed. These results, correlated with the shallow seismic survey, are useful in defining anticipated penetrations and anticipating areas where punch-through can occur.

■ *METHODS OF ANALYSIS* The equations used to determine the static and dynamic stresses which will be encountered by a jack-up rig have been experimentally verified for only a few simplified cases and could be different when considering a complex braced structure in a wave train. The methods are particularly at variance in calculating extreme forces from breaking waves. In addition, difficulties arise in calculating the drag coefficients of jack-up legs and in predicting wind forces on the legs when the unit is afloat. Even though there are still discrepancies between expert opinions on these matters and in the matter of evaluating the safety of a rig, or the comparative safety of one rig over another, it is imperative to use a consistent method of calculation. Comparing rigs on the basis of advertised criteria means little if the designers used different methods of calculation.

The actual and effective penetrations anticipated on site can also affect the results. In general, designers of the independent-leg rig have assumed that the legs are pinned three metres below the bottom and no fixity accrues from the penetration into the seabed. In areas where penetration is high, this may indeed be conservative, but in areas of shallow penetration, it can be dangerous to assume a fixity at the seabed unless a sufficiently detailed study of the particular location shows it to be a reasonable assumption. Further difficulties may arise where the jack holding capacity is not capable of withstanding the required preloading weight necessary to ensure that the rig will not punch through during storm conditions. For such units, it would be necessary to examine the soil information with great care to assure no significant further penetration would ensue.

One frequent difficulty with specifying a rig which only states maximum water depth conditions, without some qualifying statement about shallower conditions in the same area, is that the rig may not be as capable in shallower conditions. Some designs incorporate scantlings which are adequate for the specified loadings at the top of the legs and also relatively strong at the bottom to withstand towage loadings. In the centre is an area of lighter scantlings which may give a performance discontinuity. This could mean the unit is capable of operating in deep water but cannot operate at a shallower location in the same area.

■ *TRANSPORT CONSIDERATIONS* Moving a jack-up rig is a major activity requiring experience which has to be gained in marine disciplines, and skills which are often alien to the drilling industry. Ocean transports require considerable study, planning, effort, and cooperation between the owner, marine surveyor, and transport contractor to ensure a safe arrival. For many years, the only method available was the wet ocean tow where the rig is towed, floating on its own hull, by one or more ocean-going tugs. Due to the short, blunt shape of jack-up hulls and their limited seaworthiness, wet tows are slow and fraught with difficulties. The causes of accidents during wet tows can be generally classified under two headings: human errors and bad weather. Bad weather, in itself, seldom causes major jack-up accidents; when coupled with human errors, it can and has produced serious damage.

In 1973, the first dry tow of a jack-up was made from Italy, around the Cape of Good Hope, to Dar es Salaam over a distance of 15,932 kilometres. In a dry tow, the complete rig is loaded on a special submersible transport barge and towed by an ocean-going tug. Due to the better shape of the barge, towing speeds are higher and the seaworthiness of the combination is better. A recent improvement in dry rig transport has been the development of special self-propelled submersible transport vessels, providing an even faster and safer method of transport.

A field or location move is a move from one drilling site to another within a local area of operation. The tow must be completed within a reliably forecasted good weather period; normally, the rig can make its field moves with the legs either fully raised or partially lowered. The towing route must be planned carefully with sufficient water depth available at low water, especially if the rig is towed with the legs partially lowered.

Good preparation of a jack-up rig for a field move covers many aspects. The legs, the tie down of equipment, cantilevers, substructure, drill structures, deck cargo, drill pipe, and casing must be able to withstand the unit's roll and pitch during tow. As a lack of watertight integrity has been a significant contributing factor in many jack-up accidents, the platform must be thoroughly prepared to prevent the ingress of water into void, preloaded, or other compartments. Since the jack-up unit spends only a small percentage of its operating life afloat, special attention must be paid to all closures. Of paramount importance in any move is the selection of crew with appropriate towing experience. Ideally, the tug should place one or two experienced seamen on the jack-up, so that there is adequate communication and experienced personnel are available in case a reconnection of the tow line is necessary.

In the Gulf of Mexico, the risks encountered during field moves are much lower than those in Canadian waters because the towing contractor can often call an additional tug for assistance or fly out spare tow lines and parts in the event of problems. Operating in Canadian waters is much more akin to operating in the North Sea, where these facilities are generally less available at short notice.

■ *STORM PREPARATIONS* All jack-up rigs are designed for certain survival criteria involving a combination of a maximum wind speed, wave height, and current. Sometimes the rig can only withstand the storm after various special preparations have been made. To avoid overstressing the legs, it is usually required that the longitudinal centre of gravity and transverse centre of gravity of the platform, drilling structure, and variable loads are near the centroid of the legs. This assures that each leg will carry an equal amount of platform weight and that the safety factor against overturning is optimal in all directions. In some cases of extreme loading, it may be necessary to add ballast water to the platform to increase the safety factor. In some designs, the operations manual may require that the cantilever is retracted when a severe storm approaches. The extent of the effort required for retracting the cantilever and its possible effect on the drilling operation and well

control must be taken into account. Some designs may need to limit the variable loads on board so as to avoid overstressing the legs during storm conditions; this means that liquid consumables such as drill water and mud may have to be dumped every time the unit is prepared for survival conditions.

In areas where storms are frequent, it is often very difficult to make these preparations within a reasonable time, especially when the severity of the storm may not be known in detail until a few hours before it reaches the rig. It may be prudent not to allow rigs to work at these locations unless they are designed to weather the storms with their cantilevers extended.

■ *ACCIDENTS* Of all types of MODUs, jack-ups are the most vulnerable to damage and destruction and account for about 68 percent of all accidents. A large number of the accidents involving either jacking up or down or being towed from one location to another have been sustained during fair weather. In fact, more towing accidents have occurred during fair weather than in rough weather. The majority of accidents during jacking are due to punch-through which is rapid, uneven penetration of one leg during initial jacking up of the platform and preloading. Between 1980 and 1984, there were at least ten severe incidents involving punch-through of jack-up rigs; very likely, the actual number is higher since not all incidents have been publicized. Punch-through is usually caused by irregular soil layering or unusual soil features. A thorough and careful inspection of the site significantly reduces the likelihood of punch-through.

■ *CONCLUSIONS* Jack-up platforms are exceedingly useful tools for exploration in the eastern Canadian offshore. Unlike floating units, the integrity of the structure is very dependent on the specific location at which the unit is operating. An accurate assessment of the oceanographic environment for the location is essential. Designs are currently being produced for the extreme conditions encountered in Canadian waters. It is essential for safe operations that independent assessments are made to establish the safety of the units for specific sites and environments. It is the task of both the designer and the builder to produce a jack-up which is suitable for the rigors of operation and transit, but it is the responsibility of the owner to operate the unit within the stated limitations of the design. The barge engineer and the other responsible personnel will have to be fully aware of the stated and implied limitations and must demonstrate sound understanding and marine judgement in order to prevent accidents. The best safety feature for any platform is skilled and knowledgeable rig management.

Summary of Model Testing Seminar

The Royal Commission undertook a series of model tests of the semisubmersible *Ocean Ranger* during the process of completing its Part I mandate. The tests, carried out by hydraulic laboratories in Canada and Norway, proved to be of significant value in determining the reaction of the rig to the environmental forces and operational loads which existed on the night of the accident. On December 14, 1983, the Royal Commission convened a one-day seminar to investigate the potential value of hydraulic and aerodynamic modelling as a means of assessing the safety of MODU designs. The participants were chosen to provide a range of views on the subject, and included theoreticians, practitioners, and users of model testing techniques.

The participants took two distinct approaches to the subject of model testing in MODU design. To the designer, model testing is a tool used together with numerical and other methods as a means of evaluating specific designs; the cost and accuracy of numerical modelling has improved substantially in recent years with advances in computer technology, making widespread use of hydrodynamic and aerodynamic model testing relatively prohibitive. To the theoretician and physical modeller the same data processing developments have allowed more detailed analyses of test results and improved accuracy in wind and wave modelling and in real-time data measurement. In short, the field of model testing has been advanced by the same technology which has threatened to limit its use.

It was noted several times that there are many instances of disagreement between the results obtained from numerical and physical techniques, ranging from discrepancies in predicting the air gap in semisubmersibles to the difficulty of establishing the wind forces encountered by floating offshore structures. Further problems were seen when comparisons were made with full-scale measurements, and it was generally acknowledged that very little full-scale information returns to the modeller or the designer. One participant suggested that the iterative nature of the design process demands a totally integrated approach, consisting of theoretical work, experimental modelling, numerical simulation, and full-scale measurements. By understanding the relative strengths and weaknesses of each method the designer can benefit from the results.

A major point of discussion was the application of model testing in the development of regulatory design criteria, particularly with respect to stability. The fact that existing criteria are based on empirical methods and do not have a rational theoretical basis seemed to be of less concern to the designers than to those who actually carry out the testing. It was suggested that, although, satisfactory, theoretically-based stability criteria for semisubmersibles would probably not be available in the foreseeable future, every effort should be made to achieve a better understanding of the dynamic principles involved. This area of discussion highlighted the major thrust of physical modelling programs, that of dealing with dynamic factors in situations where only static or quasi-static numerical methods exist. Model testing in MODU design finds its greatest application in examining vessel motions, mooring forces, and towing resistance.

The *Ocean Ranger* model tests provided a challenge to state-of-the-art techniques and encouraged the development of refinements to those techniques. For instance, the simulation of wind loading, with allowance for gusting, was based on a series of aerodynamic tests carried out by the National Research Council (NRC) in Ottawa. The NRC Hydraulic Laboratory modelled the resultant wind forces by using elastic braided filaments connected to the model so as to exert varying loads dependent on the rig's instantaneous position and attitude, the air gap, and the

mean wind speed and gustiness. The Norwegian Hydrodynamic Laboratories (NHL) in Trondheim used computer-controlled fans to achieve the simulation. Representatives from both laboratories gained significant experience in the application of these techniques, and, although neither group was prepared to suggest which method might be preferable, the resulting data do provide a basis for analysis. The testing program also pointed out areas for improvement in techniques and measurement. Those participants involved in the testing program carried out for the Royal Commission noted that the tests and the large body of data which entered the public domain at the completion of the Part I report, provide a basis upon which further analyses should be undertaken.

It was evident from the comments of all participants that model testing will continue to be an integral verification process in MODU design, and that the exchange of information between all parties involved would be of significant value.

4

SAFETY MANAGEMENT

SAFETY MANAGEMENT

INDUSTRY SAFETY MANAGEMENT

An Evaluation of Industry Safety Management in Eastern Canada Offshore Drilling Operations
Manadrill Drilling Management Inc.
Calgary, Alberta
June 1984

There has been a significant degree of improvement in the safety of offshore operations in Canadian waters over the past few years. Industry and government are working together in several key areas and new ideas, equipment, and training programs have been implemented. The most significant development has been the marked improvement in safety awareness on the part of employees, supervisory staff, and senior management.

The Canada Oil and Gas Lands Administration (COGLA) has matured significantly since its inception. Industry has grown to accept that COGLA can be an effective control mechanism and is working with the regional and head offices. Regulations, guidelines, and requirements issued between 1982 and 1985 are being observed by industry to the satisfaction of government agencies. The operators have made significant progress in developing an effective voice through the amalgamation of the Canadian Petroleum Association and the East Coast Petroleum Operators Association to form the Canadian Petroleum Association Offshore Operators Division, an effective operations-oriented group that has the support of industry management and the respect of the government agencies. There has also been a definite relaxation of some of the controversial issues, for example, local employment and goods and services, that had earlier undermined the working relationships between government and industry.

The areas that still require attention and that give rise to varying degrees of concern are generally marine oriented or non-drilling issues. These range from a general or overall concern about the administration of marine operations on Canada's Continental Shelf, outside the 12 mile limit, to some very specific concerns around basic offshore industry practices and procedures. Many of the concerns are common to both industry and government.

The lack of a consistent approach to the administration of activities in Canada's Continental Shelf waters is one of the main concerns facing industry and government agencies. There will continue to be a significant amount of confusion, duplication of effort, inconsistent interpretation of regulations, and the possibility of an oversight leading to a serious accident, until this basic legal question is answered. A strong working relationship between the drilling contractors, the owners and builders of the drilling units, the Canadian Coast Guard (CCG), and COGLA is essential to the administration of a strong safety regime. That relationship cannot be expected to develop without a basic definition of the Coast Guard's responsibilities and roles which are in turn directly related to the country's overall administration of its waters.

■ *EQUIPMENT AND SERVICES* The philosophy and the technology related to lifesaving equipment systems and procedures are not as advanced as those regarding drilling and well control. The systems in use for the evacuation of personnel from a MODU in rough weather conditions are inadequate. There is a significant amount of work being done to improve the industry's capability in this area, but this work has been left to the conventional marine equipment manufacturers. Industry and government should take more active roles in the development of systems tailored to the unique needs of the offshore drilling industry.

One specific type of safety equipment that needs reconsideration is the helicopter immersion suit. These suits are less bulky than the survival suits generally provided on drilling units because they are worn on a daily basis and because they provide the manoeuvrability needed if a person is to escape from the cabin of a downed aircraft. The suits do not provide the same degree of thermal protection as regular survival suits, and this is seen as a problem since helicopter accidents are considerably more frequent than abandon-rig situations.

The risk of collisions between supply vessels and MODUs should be lessened as design improvements are made in supply vessel mooring and propulsion control systems. Emphasis is being placed on the need for supply vessels which are designed and built as MODU support craft rather than modified to this use from diving or construction support applications. Concern was also expressed about the adequacy of the qualifications required for the senior command positions on board supply vessels operating in Canadian waters. Personnel from the merchant marine and the fishing industries require special training and a significant amount of on-the-job experience before they are qualified to operate these sophisticated and specialized vessels alongside MODUs.

Concerns were expressed on the part of some of the contractors with respect to the deployment and dedication of supply vessels in the standby role. Supply vessels double as standby vessels in most East Coast operations. Contractors feel that the standby role may be compromised from time to time when vessels are changing functions at the rig. Should an emergency occur while the supply boat is offloading, for example, it may not be in a position to respond immediately in its standby role.

A second area of concern with respect to the use of supply vessels in the standby role has to do with the effectiveness of their recovery equipment and techniques. Industry has adopted the latest, state-of-the-art equipment but industry and government agencies both expressed concerns that the level of training and development of the support vessel crews is not in keeping with the stage of evolution of the equipment. Training requirements should be established and facilities provided to ensure that these crews are well versed in the use of the equipment. The industry should also investigate the development of a set of standards that would guide the support vessel crews in rescue exercises.

■ *SAFETY PROCEDURES* There currently exists a basic disagreement between industry and government on the philosophy of conducting emergency lifesaving drills and exercises on board drilling units. One school of thought advocates some form of regulatory control forcing the contractor to hold these drills on a random basis to eliminate the complacency theoretically created when drills are conducted on a scheduled basis. The opposite school of thought, which includes all of the drilling contractors and most of the operators, believes that random drills do not remove the tendency to complacency and, in fact, can create unnecessary hazards to onboard personnel. It is essential that industry reach a consensus on this very basic element of safety training before unacceptable systems are either adopted or regulated by operators or government.

The philosophy of planned evacuation of MODUs prior to impending bad weather requires serious review on the part of both industry and government. The

policies and procedures currently in effect were adopted by industry as the result of political and public pressures. The procedures are inconsistent and the basic philosophy is not universally accepted by either the contractors or the operators.

■ *TRAINING AND DEVELOPMENT* An area of concern that is shared across industry and within government, relates to the onboard command hierarchy in effect on MODUs. COGLA issued a set of guidelines in late 1983 which specified that floating drilling units require an individual responsible for the safety of the unit, qualified in marine matters, who possesses a recognized Master Mariner's Certificate. Although industry has complied with this guideline there is a great deal of controversy over the issue.

Many contractors and some operators' personnel find it difficult to imagine that the forced introduction of a Master Mariner into an organizational hierarchy based on the drilling-oriented management style in use in the Gulf of Mexico, will necessarily improve safety. In fact, this type of action could create enough confusion and misunderstanding to jeopardize the safety of the unit. This issue requires an in-depth evaluation to arrive at a rational solution as soon as possible.

The training and development of offshore personnel has been an area of particular concern to operators, contractors, and government. The most controversial aspect of this issue has been the pressure placed on the industry by government to employ local residents. These pressures are applied directly through the operators in the exploration agreement process. The operators in turn, pass the issue on to their contractors who, in fact, employ most offshore workers. It is generally recognized that industry and government have made considerable progress in adopting the best equipment, systems, and procedures available for use in exploration activities. Equipment and systems, however, are only as good as the people who operate them. If the people are poorly qualified, if they are unfamiliar with their company's procedures and philosophies and if they are not highly performance- and team-oriented, the best equipment available is of little benefit. Interference in the proven, logical, and acceptable industry training practice by manpower agencies whose objectives have been at best somewhat myopic and at worst highly political, may create situations that are hazardous or even catastrophic.

Government manpower and employment agencies require a thorough understanding of the basic employment issues that characterize the drilling industry in order to ensure that the guidelines and regulations they develop are realistic. These issues include the fact that it is the production phase of offshore development that is labour intensive, not the exploratory phase; drilling contractors have proven over the past decade that they will recruit local personnel through the simple rules of supply and demand, and basic economic reality, without political pressure.

The development of a marine emergency training process tailored for the Canadian industry and its operating environment has been a particularly trying experience for all parties involved. The need for a basic universal procedure that prepares personnel for offshore assignments is common to government and industry. After a number of false starts by government agencies, an understanding has been reached with industry, and a commitment made that should lead to the establishment of a program that is tailored to the specific Canadian environment and to the equipment, systems, and emergency safety procedures in use by the offshore drilling industry.

■ *OVERALL EFFECTIVENESS* Many of these individual concerns can be traced to the overall control system and the degree of isolation that system has created for the drilling contractors. The weaknesses in the system are generally in the marine equipment and operations area, in the employment and development area, and in the safety aspects of both areas. These issues lie within the realm of responsibility of the contractors who own and operate the marine equipment and who employ

and develop the personnel. Both areas are highly specialized and to a large extent peculiar to the offshore drilling industry, in general, and to the drilling contractors specifically.

The problem facing industry and government is that the drilling contractors are officially isolated from those agencies in the control regime who are responsible for marine and personnel issues. The regulatory control hierarchy places two major components, COGLA and the operator (the contractor's client), between the drilling contractor and the Canadian Coast Guard on marine issues, and the Canada Employment and Immigration Commission (CEIC) on manpower and training issues. Neither COGLA nor the operator have the necessary expertise to deal with these highly specialized issues, but because of the one window, one-voice-control philosophy, they are put in a position where they are making decisions and developing control mechanisms without formal effective input from the contractors.

These problems can be solved without affecting the basic structure of the control regime. The prime requirement is an effective direct communication link between the drilling contractor and those agencies specializing in marine and employment issues. The development of a system that clearly defines the roles and responsibilities of these secondary agencies will eliminate much of the confusion that exists on the part of industry and many of the agencies themselves. This step would provide the control framework and the communication loop necessary to directly connect all principal players in the control regime while maintaining the primary contact between COGLA and the operator.

Industry and government should also investigate the possibilities for the exchange of personnel in hands-on work assignments of one- or two-years' duration to give employees a strong working knowledge of the opposite side of the control regime. This arrangement could form an integral part of employee development schemes for both government and industry.

COMMAND STRUCTURES

Assessment of the Normal and Emergency Command Structures Relating to Drilling Systems for Eastern Canada Offshore Drilling Operations
Currie, Coopers & Lybrand
Calgary, Alberta and Halifax, Nova Scotia
July 1984

Command structures vary in response to regulatory demands and also to the requirements of the different rig types and their modes of operation. On a jack-up rig, a senior toolpusher (or a rig superintendent) commands the unit while it is drilling, while the barge master on board is responsible to the toolpusher for safety, logistics, and lifeboat operations. The command of the jack-up is formally signed over to a certified rig mover when the rig is being moved or under tow. All drill ships, whether anchored or dynamically positioned, are required to have a Master Mariner on board and in full command, although on an anchored drill ship, the senior drilling person may be in command during drilling operations.

Semisubmersibles always have a marine captain on board except in the United States where an accepted equivalent is a person with a Limited (Column-Stabilized) Master's ticket. The command structure, however, is not always clear as it depends on whether the rig is drilling or in transit, and on the regulatory regime under which it is operating. As with jack-ups, where the captain does not have full command at all times, the captain of a semisubmersible, in most instances, has full command only while the rig is being moved and during an emergency situation. When a semisubmersible is in the drilling mode, it is usually the senior drilling person who is in command. This is not true for Norway, however, where the Marine Captain, who also has drilling qualifications, is in overall command at all times.

■ *COMMAND QUALIFICATIONS* Although many improvements have been made in recognizing the importance of command structure to the offshore drilling industry, there are a number of areas where confusion still exists or where changes need to be made. A shared or divided command system could lead to potential confusion and a weakened emergency response. A strong, unified command with a blend of marine and managerial skills, attitudes and experience would seem to be most suitable in the Canadian context, but there is a serious shortage in the supply of people qualified and available for such command positions. This situation could be improved by establishing offshore drilling as a specialty section of Canadian marine training with specific theoretical and practical subject matter related to drill ships and semisubmersible drill rigs. Industry has already commenced discussions with the Coast Guard to see if drilling personnel can be trained in marine operations aboard Coast Guard vessels and if Coast Guard captains can be trained on board drilling rigs in drilling operations. This type of interchange would assist in improving the skills available to the industry. In addition, it would greatly enhance the Canadian Coast Guard's understanding of rig operations and design principles.

As part of this recognition of the qualifications required to assume a MODU

command position, industry-wide standards and a certification process should be developed. Training and certification programs should also be required for other key positions including senior drilling staff, first mates, captains, ballast control operators, and lifeboat captains.

Until there is agreement on the qualifications and standards required for semisubmersible and drill ship commander positions, and until certification programs are developed and the supply of qualified rig commanders is adequate, command structures which are not completely unified will continue to exist. In the interim, command structure documentation should recognize clearly those aspects which will be delegated by one individual to others in the chain of command and the limitations of authority involved in each instance.

■ *EMERGENCY SITUATIONS* It is also important that the command structure for normal operations support the structure which will be required in emergency situations. Even though the captain may have delegated substantial responsibilities to the drilling supervisor while drilling operations are being carried out, he must remain active in terms of coordinating the overall safety program, supervising support functions such as maintenance, and conducting emergency drills. In this way he will be seen as the ultimate "safety commander" and authority in marine and overall rig safety matters. Emergency response plans should indicate clearly the alert conditions which trigger the assumption of full active command by the captain. Guidelines for the development of clear organization charts should be developed by industry for different command structures. The adoption of common documentation practices and methods of showing lines of authority, functional relationships, and advisory relationships between elements in the drilling system would be beneficial to a uniform understanding of emergency response plan and command structure documentation.

Further work should be carried out in identifying the specific conditions which trigger alert stages, and in defining activities to be undertaken at each stage by the command structure. The alert stages of current industry emergency response plans are not adequately defined for onshore personnel, nor are the heavy weather conditions for an onboard alert clearly stated. Also, the conditions under which government Search and Rescue becomes actively involved are not indicated. Decision-making by industry in response to a particular emergency is most effectively made at the site of the emergency. This should be clearly stated in company emergency response plans which currently imply that key decisions are to be made by shore-based managers. While industry has developed a formal "mutual aid" system which significantly enhances any rescue operation, it remains necessary to ensure that Canadian marine and air search and rescue services are fully aware of the industry's emergency response plan and that onboard drills are carried out regularly and effectively.

Industry sources indicated that safety drills on board most rigs provide adequate training for individuals to carry out their normal duties in an emergency situation. These exercises should be conducted periodically, however, to ensure that back-ups for key positions also understand how to carry out the duties of their superiors should they be injured or otherwise unavailable during an emergency. This requirement is particularly important considering earlier findings that the overall level of training and experience among those in back-up positions is significantly less than that of those in charge.

Exercises involving Search and Rescue, the Coast Guard, and other government regulatory agencies have been carried out. It is particularly important to test the procedures and communication systems involved in these exercises as close logistical support among independent units will be required during emergency situations. In this regard it might be useful to implement regular interval drills at all levels in the command structure, and to require that simulated emergency exer-

cises involving Search and Rescue, the Rescue Co-ordination Centre and Coast Guard, be carried out by each rig at least once per year. Exercises aimed at testing the effectiveness of the joint operator alert response plan should also be carried out on an agreed frequency basis. These exercises would be designed to test inter-operator communication systems, emergency response readiness of designated helicopters, emergency response readiness of other operator supply boats, as well as other elements of the system such as the functioning of Sable Island as an emergency base.

COMMUNICATIONS

Assessment of the Means of Communications in Relation to Eastern Canada Offshore Exploratory Drilling
NORDCO Limited
St. John's, Newfoundland
July 1984

A drilling unit needs to maintain long and frequent communications contact with its shore base. The type of communications services needed and provided on a drilling unit include voice, telex, or teletype, telecopier or facsimile, and data. Both the drilling unit and its shore base also need to be capable of voice communications with transport helicopters and support vessels. The ship, shore, and helicopter stations are required to meet a fairly comprehensive and detailed set of regulations under international, Canadian, and other flag state conventions. These include the *International Telecommunications Regulations* (ITR), the *Canadian Radio Act* (Department of Communications), *SOLAS Convention*, the *Canada Shipping Act* and its component regulations, the *Canadian Aeronautics Act*, and relevant sections of the *Canada Oil and Gas Drilling Regulations*.

■ *REGULATORY STANDARDS* A question exists as to whether communications systems on drilling units should adhere to regulations pertaining to passenger or to cargo vessels. Standards are now being prepared by the Canadian Coast Guard to address this problem and to determine whether Canadian regulations apply to vessels or MODUS operating outside the 12-mile coastal limit but within the 200-mile territorial limit.

Pertinent regulations of the *SOLAS Convention* must be adhered to by the vessels whose flag state is a signatory to the convention. For vessels and MODUs operating in Canadian waters offshore, a request must be received from the country of registry before an inspection takes place and radio certificates can be issued under the *Canada Shipping Act*. Ships registered in countries that are not signatories of the *SOLAS Convention* must be inspected under the *SOLAS Convention* and the *Canada Shipping Act* for customs clearance purposes but radio certificates are not issued. The *Canada Shipping Act* applies to all ships operating in Canadian waters and its regulations are more stringent than those practised under the *SOLAS Convention*. The specific equipment requirements under the *Canada Shipping Act* are determined by the frequency zone in which the vessel is operating.

■ *DESCRIPTION OF PRESENT SYSTEMS* Helicopter communications are covered under the *Canadian Aeronautics Act* which states that two-way voice communications must be maintained with control central throughout the flight. The aircraft is also required to carry an emergency locator transmitter and, under instrument flight rules (IFR), a radio direction finder. Equipment specifications, however, are not included.

Most drilling units operating off eastern Canada in 1984 have satellite communications terminals (mostly linked to INMARSAT), which provide voice, telex,

facsimile, and data communication services. Satellite communications facilities are being used even though there are no regulations which make them mandatory. These terminals, through geostationary satellites, provide a highly reliable link to the shore base. The satellite terminals are equipped with an emergency override channel which provides immediate and automatic access to shore when activated. As with most communication links, (except cable links), the size, positioning, and stabilization of antennas are important features in maintaining communication reliability. Stabilization of the ship or drilling unit antenna in relation to satellite position must be maintained regardless of the pitch or roll of the vessel.

Because of high satellite user costs, the prime communications among the components of a "drilling system" are basically provided by MF/HF and/or VHF links. Of the two links, the VHF link is more reliable but is effective only within line-of-sight (up to approximately 80 kilometres). This primary link is used in the coastal exploration zone including Sable Island and the Scotian Shelf. The MF/HF links utilize ground- and/or sky-wave mode of propagation. The effective range of the more reliable ground-wave mode is approximately 350 kilometres. The ground-wave mode is prevalent for drilling operations in the middle exploration zone including Hibernia while the longer range, but less reliable sky-wave MF/HF mode is used in more distant locations such as offshore Labrador.

The range and quality of communications by means of the above links may be degraded due to environmental phenomena such as lightning, rain, snow, wind, and sea ice. The VHF links suffer the least while the MF ground-wave propagation links may be severely affected during storm conditions. The reliability of HF sky-wave links is affected by variations in ionospheric conditions which may introduce significant noise during the night.

The communications link with helicopters is primarily provided by the VHF aeronautic band while the prime link with support vessels is provided through the VHF marine band. Both helicopters and support vessels carry MF/HF equipment as well. These links are somewhat weaker than those between the drilling unit and the shore base because the latter are reinforced by the satellite link. All the above links have multichannel capability, thus providing transmission/reception frequency redundancy. In particular, on drilling units and shore bases, multiple antennas and receivers and spare transmitters are provided, with automatic selection and switchover capability. Adequate back-up or emergency power is provided through lead acid batteries.

Although any two components of two nearby networks may not share a common private frequency, communication is possible through a number of frequencies provided on the VHF, MF, and HF bands for public correspondence. Special call frequencies may be used to establish a common working link for temporary use through an intermediary Coast Guard station. These stations are required to maintain a continuous listening watch on international distress and calling frequencies (500 kHz – telegraph under the *SOLAS Convention*, 2182 kHz, and 156.8 mHz). Most ship stations are also required to maintain this watch.

■ *RESEARCH AND DEVELOPMENT* Research aimed at improving satellite and other methods of communication is ongoing. Meteor-burst propagation systems in which VHF and Ultra High Frequencies (UHF) are propagated by reflection from columns of ionization are being examined. One-way communication of voice and facsimile has been tested, as have two-way telegraph circuits which operate over distances of 800 to 2,000 kilometres. Other developments are the radio telephone with automatic channel evaluation (RACE), which utilizes switched telephone systems, and the mobile satellite systems (M-SAT) which allow transmission of text messages over vast distances. RACE does not appear to be capable of providing high quality voice or data circuits, while the M-SAT system is still in the feasibility and design stage with anticipated demonstration service available between 1986 and 1994.

■ *CONCLUSIONS* The communications systems presently used offshore are reliable and appear to be adequate to meet the needs of exploration companies. It would enhance safey considerations, however, particularly in emergencies to equip helicopters with VHF marine band radio equipment and/or standby vessels with VHF aeronautic band equipment thus permitting immediate communication between the two support services. Drilling units, particularly those operating at distances greater than approximately 80 kilometres offshore (which may be outside the VHF coverage area of the Coast Guard Station), should be equipped with satellite communication terminals. The costs of establishing these links might be borne by a pooling of operator resources to provide the best possible antenna facilities for a particular area. General reliability of communications systems can be enhanced by following a regular preventive maintenance schedule and having spare parts and a qualified technician capable of repairing communications equipment on board each MODU. A communications contingency plan should be prepared and made available to radio operators outlining the procedures for using communications equipment in the event of a link breakdown. The applicability of Canadian regulations to offshore drilling units, particularly those that are foreign-owned, should be clarified.

Long-term benefits would accrue from the compilation of a communication reliability data base for the study area, and from research into enhancing MF/HF and VHF communications reliability through improved antenna designs and employment of space, path, frequency, and polarization diversity.

Summary of Safety Management Seminar

The safety management practices employed by corporations to monitor and improve worker and workplace safety vary according to the management philosophy of individual corporations and the degree to which industries are regulated. On September 17, 1984, the Royal Commission sponsored a seminar which examined the topic of Safety Management. Speakers from operating companies, drilling contractors, and supply vessel owners were invited to present papers on the safety management practices used within their respective companies. To stimulate discussion and provide a different perspective, representatives from Du Pont Canada Inc. participated in the seminar. With an outstanding record of safety performance in a hazardous industry, this company is acknowledged to be a leader in safety management.

Du Pont's safety management programs have proven effective in other industries such as mining. Workers are represented on the majority of Du Pont's committees and management selects the members of the safety committees with the objective of getting the best people involved regardless of their affiliation. Some plants' safety management programs have been developed by groups of workers with the assistance of a supervisor. This gives the workers a sense of ownership and commitment to the program, and this in turn has a significant effect on program results. Du Pont has not found it necessary to establish a policy on refusal to work because management deals with the workers' perceived risks as well as the actual hazards identified.

The operators and drilling contractors indicated that all levels of management are responsible and accountable for safety performance. While the chief executive officer is considered ultimately accountable for a company's safety performance, the individual workers are also responsible to perform their duties in a manner which is safe to themselves and to their fellow workers.

With the primary emphasis being placed on the prevention of accidental occurrences, the industry gives safety a high profile in a number of ways:

- Making it an integral part of each operation through regular safety meetings;
- Providing a safe working environment;
- Ensuring that appropriate work standards are established and followed;
- Providing funding for improved equipment;
- Providing continued safety training of personnel;
- Developing joint emergency response plans and exercises.

Most companies utilize formalized safety audit programs to verify the success of safety efforts in their operations. Successful safety management requires demonstration of commitment to safety by top management. Worker involvement in safety management programs including safety committee meetings and safety award programs appear to be standard practice in the industry. Safety meetings involving all employees provide a forum for hazard identification by workers, and for review of actions taken in response to previously identified hazards.

The regulatory authorities hold the operator responsible for the safe completion of the approved drilling program, and consequently, operators require their contractors to meet and maintain specified safety standards. Operators take the initiative to monitor the safety programs of their contractors. A government representative suggested that the safety management programs of operators and drilling contractors are the keys to accident prevention and effective emergency response. It was unanimously recognized that government regulations at best

represent minimum standards.

A drilling contractor suggested that the regulatory agencies should assume the role of a certification board for training courses which are necessary for the safe and efficient operation of MODUs. The curricula and examinations for training courses should be primarily developed by the industry; the regulatory agencies should ensure that the curricula are appropriate, that the examinations are rigorous enough to ensure student proficiency, and that training institutions are accredited. The Canadian Petroleum Association (CPA) stated that of the 34 positions outlined in the report *Guidelines for Minimum Training Qualifications/Standards (Floating Units Only) MODU Crew Personnel for Operation on Canada's East Coast*, those which overlap the marine and drilling disciplines should be certified by industry. The certification of marine qualifications by the Canadian Coast Guard is a well established and accepted practice. The operators recognized the need for periodic recertification for certain qualifications to ensure that workers maintain a high level of competency. It was suggested that industry would, without excessive regulation, continue to develop training courses by means of industry certification and recertification.

Both industry and government representatives agreed that the collection and analysis of accident statistics need to be improved. CPA has undertaken a data collection effort for the East Coast drilling operations and COGLA's Medical Advisory Committee has initiated a study to determine appropriate parameters for a data collection system. At present, COGLA provides feedback to industry after a government analysis of accidents if it is judged appropriate and provided confidentiality of an operation can be maintained.

Representatives of Du Pont, which has operations in over 30 countries, reported that regulations have had no impact on the company's safety practices as it maintains a safety standard which exceeds regulatory requirements. A representative of Du Pont suggested that governments should redirect their efforts to improve occupational safety by developing and clearly expressing specific objectives and demands for performance, and by developing a consistent statistical base to measure performance. Du Pont suggested that merit ratings for companies, based on safety performance, should be considered in workers' compensation assessments.

It was recognized that operators' health and safety departments perform complementary functions yet safety departments are well established compared to occupational health departments which have only recently been given broad management guidelines and scope. Drug and alcohol abuse have been recognized by industry as potentially significant problems in the offshore industry. Preemployment screening and intensive security clearance systems, for screening personnel prior to departure for offshore rigs, are used to control drug abuse. Some operators have established assistance programs for personnel with chronic drug or alcohol abuse problems, and the CPA conducts ongoing reviews of drug and alcohol problems through its various committees.

A standby vessel contractor suggested that fast rescue craft training is a primary means of improving safety performance. An operator suggested that there is a need to assess the performance of safety equipment prior to requiring its installation by law.

5

TRAINING

TRAINING

MARINE AND SAFETY TRAINING

Marine and Safety Training in the Eastern Canadian Offshore Petroleum Industry
College of Fisheries, Navigation, Marine Engineering & Electronics
St. John's, Newfoundland
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The operating efficiency and performance record of any industrial activity depends on an appropriately designed system and properly trained personnel. Unless an activity is totally automated, it is necessary to have personnel who have either acquired specific job skills or have the potential to acquire the necessary skills through training and experience. The offshore drilling industry is a rather unique industrial activity simply because it takes place in a marine environment. Consequently, the industrial system on a MODU is designed to cope with operating constraints which do not occur in typical onshore industrial activities. Similarly, persons working offshore must possess job skills that in some instances require knowledge, training, and experience in two distinct areas: marine operations and drilling operations. Since offshore drilling is a relatively new industrial activity the workers who possess the optimal blend of marine and industrial skills are limited. There should, therefore, be a concerted effort made by the industry and government to develop training programs which will ensure that personnel will be able to perform their duties safely and effectively.

Differing attitudes towards offshore training in the United States, the United Kingdom, Norway, and Canada, result in a diversity of approaches and funding practices. The Norwegian model is based on the belief that society must accept responsibility. Therefore, in Norway the government plays an active role in regulating not only marine and industrial training for MODU crew members, but also safety training. Generally the funding of these programs is provided by the government. In the United States, however, the amount of government control is very limited. Certain regulatory requirements exist for senior marine and industrial personnel. The mode of training and funding are entirely the responsibility of industry. In the United Kingdom, the administration and funding of offshore training have changed over time. Initially the government set up and supported training boards whose role it was to organize and administer programs for the industry. Funding for these boards and their training programs was received from levies imposed on industry. Industry associations have now taken over control of the training boards and programs are arranged as requested by members of the various industry associations. Several commercial training institutions provide a wide range of specialty courses, notably in safety and survival training.

In Canada, regulatory requirements governing offshore training have tended to be general in their application. Before the loss of the *Ocean Ranger*, there were specific well-control training requirements for senior drilling personnel, but marine related requirements and specialty training programs (survival and safety related)

were not mandatory. Since 1982, regulators and the industry have focussed specifically on the training needs of offshore workers. Industrial training programs, funded by industry, have been developed for offshore workers by the Petroleum Industry Training Service (PITS). Specialty training programs have also been developed by both public educational establishments and by commercial training institutions. These programs cover basic emergency and survival training and are funded by fees levied on participants. There is no mandatory government standard for these safety training programs.

To ensure safe and efficient operations in the offshore industry, standards should be developed by government in consultation with the industry and training institutions. These standards should apply to personnel who are employed on MODUs, marine support vessels, and aircraft. Some attempt should be made to ensure that these standards are recognized internationally.

■ *BASIC EMERGENCY TRAINING* In the performance of their assigned duties, individuals participating in an offshore operation are responsible for acting so as to prevent hazards arising, making a correct initial response to a situation which does arise, assisting others to survive, and acting to ensure personal survival. Basic safety training endeavours to prepare personnel to meet these responsibilities, although the content and provision of such training vary widely between the United Kingdom, Norway, the United States, and Canada.

In the United Kingdom, the Department of Energy requires all persons working on a MODU on the U.K. Continental Shelf to have suitable training for their own safety. While the requirements are stated in the *Mineral Workings (Offshore Installations) Act* 1971 and the *Health and Safety at Work Act* 1974, these Acts do not specify standards. Guidelines to meet the legislated requirements have been prepared by the U.K. Offshore Operators Association (UKOOA) with the Offshore Petroleum Industry Training Board (OPITB) and recommend varying levels of safety training for different categories of personnel. The training is provided by institutions within the United Kingdom, but, because these guidelines have no legal status, operators have found them difficult to enforce on their contractors.

In Norway, all offshore workers are required to undergo basic safety training based on standards agreed to in the LEIRO II syllabus. The course requires comprehensive onshore training for two weeks supplemented by one week of on-the-job training arranged by the employer. Because this formalized training schedule is applied to all offshore workers in Norway, concern has been expressed that insufficient facilities are available to meet the training needs of the large work force. Consequently, Norway has approved at least one United Kingdom training institution to offer LEIRO training since the standards required by the United Kingdom are very similar to those required by Norway.

Attitudes in the United States towards basic safety training are different from those in the United Kingdom and Norway. There are no statutory requirements for basic safety training for personnel on U.S. registered MODUs. Indeed, most U.S. companies feel that offshore survival training is not necessary for all persons working on a unit and prefer to provide their own on-the-job training and drills to achieve a satisfactory level of competence. One factor affecting this attitude is the relatively high turnover among drilling personnel.

Although in Canada the regulations require all persons employed offshore to have some degree of basic safety training from an approved course, there are not yet any nationally-accepted standards for achieving these requirements. The Marine Emergency Duties (MED) certificate offered by the Ministry of Transport is an accepted start, but the industry considers this program lacking in specific MODU content since it was designed for shipping operations. To fill this void, the industry has proposed the five-day Basic Offshore Training (BOT) course, which

offers four levels of training for the various classes of occasional visitors and for regular offshore workers. The Newfoundland and Labrador Basic Offshore Survival Training (BOST) course which is similar to courses offered in the United Kingdom and Norway, is two weeks long, and also takes into account regular and occasional workers.

The course contents of BOT and BOST have much in common; industry and government are working towards agreement on a single national standard. They agreed that standards should include two core components: offshore hazards – fire prevention and control; and rig abandonment – rescue and survival. These standards should be offered at varying levels to established categories of persons spending different amounts of time offshore, with selected persons being provided with supplementary training in such specific areas as, for example, helicopter procedures and radio operations.

■ *SPECIALIST EMERGENCY TRAINING* The main response to various emergencies on MODUs is handled by personnel with specialist training with assistance from those with basic safety training. This approach makes it unnecessary to train everyone to a high level of proficiency in dealing with a specific situation. Also, some responses are better carried out, or can only be carried out, by a team practiced in coordinated working. Nevertheless, no country has sufficiently addressed the subject of specialist emergency training, and there are few formal requirements for personnel so trained, although in Norway and the United Kingdom, numerous courses are available and are used by the industry. Some typical examples of specialist emergency training include: damage control team, firefighting, man-overboard boat crew, survival craft coxswain, and first aid.

Specialized damage control training is required only in Canada by directive from COGLA who observe damage control teams in action to verify their capability. In the United States and Norway, senior marine personnel on MODUs receive training in basic damage control for ships as part of their marine training. In addition, in Norway, the LEIRO basic safety training course includes some instruction in damage control.

Firefighting teams and leaders generally follow the traditional marine pattern, although on MODUs selected drilling personnel may be included on a team. Norway and the United Kingdom offer advanced fire training at a number of schools, while in the United States, where fire training over and above that included in regular marine training is not required by law, some courses are available at schools usually associated with universities. Canada has no specialist courses available for MODU fire teams, and personnel are sent to the United States or overseas for such training. All regulatory bodies do, however, require helicopter firefighting training. Such courses are offered in the United Kingdom and the Netherlands.

All MODUs designate a man-overboard team to operate the Zodiac-type inflatables or fast rescue craft (FRCs) used in a man-overboard emergency. Man-overboard training is generally confined to onboard drills, since no specialized courses are available, other than those aimed at FRC teams serving on standby vessels. While in the United Kingdom the man-overboard drills for standby vessels are included in the UKOOA guidelines, neither the United States nor Canada has regulations on how the drills are to be conducted, and companies are left to devise their own standards in this area.

Personnel with special survival craft coxswain training are required in the United States and Canada, and such a requirement is also standard practice in the North Sea offshore industry. Lifeboatman courses usually take one or two days over and above basic safety training, although in the United States the course for a Lifeboatman's Certificate is five to eight days. Emphasis in these courses is on practical training in all phases of survival craft operation.

Specialist medical teams, to assist the rig medic in coping with emergencies,

are required by the contingency plans in effect off eastern Canada. Training of these personnel is generally limited to first aid.

General safety training does not sufficiently address specialist needs, especially given the isolated, distant nature of the industry off eastern Canada. Specialist facilities need to be developed in Canada, preferably at existing institutions that offer basic safety training. Since formal requirements for specialist training are few, those developed should incorporate the need for specialist personnel to participate in regular drills and to undergo periodic refresher training.

The composition and structure of the crew on a MODU varies with the type of MODU, its activity (whether it is drilling or whether it is moving on/off or to/from a drilling site), its flag of registry, and its owner's operating policies. Generally crews can be divided into three major groups: marine, industrial or drilling, and domestic support. Marine crew structures on MODUs show considerably more variance than do the drilling crews. The structure of a drilling crew is similar on all MODU types regardless of flag. The marine crew component depends upon the MODU's flag and its type.

■ *MARINE CREW* The marine crew standards on drill ships tend to be similar, regardless of registry. They have fully certified officers and trained seamen. Jack-ups usually have a skeleton marine crew on board while the rig is operating, but, when it is being moved to a new location, a special marine crew prepares the rig for ocean transit and takes it to its new drilling location. Semisubmersibles exhibit the greatest variation in marine crew. For units registered in Norway, the United Kingdom, and Canada, certified officers and seamen are required to be on board at all times, whereas for units registered in the United States, a certified marine crew is required only for long voyages, and then, only if the rig is self-propelled.

The training and certification of marine crews on MODUs also exhibit significant differences among the various jurisdictions. These differences reflect not only different regulatory philosophies but also result in different command structures. Norway, Canada, and the United Kingdom tend to regard MODUs as vessels engaged in industrial activities and consequently require certificated officers and crew. The United States, however, tends to view a MODU as an industrial site, thus they allow marine crew members to hold "industrial" licences rather than traditional "marine" certificates.

In Norway, the person in charge must always be a Ship's Master with one or two years' previous MODU experience in a senior position. The master is required to complete the six-week platform manager's course in such subjects as drilling technology and rig manoeuvring. This course provides most of the additional knowledge required by a mariner to manage a MODU. The master does, however, have a statutory duty to consult both the Drilling Section Leader and the Stability Section Leader in any circumstances which endanger the drilling installation.

For Canadian and British registered MODUs, the person in charge must hold a Master Mariner's Certificate. In the United Kingdom, Master Mariners must attend a two- or three-day Offshore Installation Manager's course, which is designed to provide information on legal obligations, rather than insight into operational aspects of MODUs. In Canada, since September 1983, Masters of MODUs are required to attend the five-day MED III course which emphasizes leadership in various emergencies. Operators of foreign-registered MODUs working on either the Canadian or United Kingdom Continental Shelf are required to nominate a person in charge, but the responsibility for ensuring that a suitable person is nominated rests with the owner and there are no specific training requirements.

The U.S. requirement for a Master Mariner, for drill ships and self-propelled semisubmersibles in passage, involves no additional MODU-specific training. For units where a qualified Master Mariner is not required, a special Industrial Master's License is mandatory. Typically candidates for Industrial Master should have four

years' service on a drilling unit including two years in a responsible position in either the marine or drilling crew, or a Bachelor of Science degree and three years' service, including one year in a supervisory position. In addition, the master must possess an approved radar training course certificate and an approved well-control certificate. The special Industrial Master's License can be obtained after only 15 to 20 days of formal training. While this type of licence is apparently appropriate for operations in the Gulf of Mexico, it does not ensure sufficient depth of knowledge for safe operations offshore eastern Canada.

The person in charge must fully appreciate the relationship between drilling activities and the marine operation as well as the capabilities and limitations of the unit. Neither a master nor a toolpusher without special training in the operations of a specific MODU type can be assumed to have all the knowledge needed to command a MODU. Canada has, at present, no system for conducting, approving, or certifying either MODU-related training for masters or marine training for toolpushers. Consideration should be given to establishing a course which would familiarize licensed masters with drilling operations and the special characteristics of MODUs and provide them with a "MODU Master" endorsement. For a jack-up unit on station, the toolpusher could be the person in charge provided he has completed a course which familiarizes him with eastern Canadian offshore conditions and marine emergency duties.

The first mate on a MODU is generally required to have an appropriate marine certificate. Norway is the only country which requires a mate to receive additional training in stability and MODU operations. On U.S. registered MODUs persons with an "industrial" licence are acceptable under most circumstances. Canada does not require additional training for mates other than that obtained during their traditional marine certification program. Although the mate's standard training is a good foundation, it does not address the special features of MODUs. Advanced training should be required in stability, MODU operations, firefighting, damage control, man overboard, and the deployment of survival craft.

There are as yet no widely accepted standards for training ballast control operators (watchstanders). Internationally there has been a great deal of activity in developing new courses. Many focus on the stability of semisubmersibles, which in itself is not sufficient. In the United States there are no legal requirements for training ballast control operators, although one training institution does offer an intensive course using a simulator and self-instruction workbooks. There are also no specific requirements in the United Kingdom for their training and certification. The owners are expected to provide suitably competent persons to ensure safe operations.

Norway has the only formalized training program for ballast control operators. Areas covered in their training include control room operations and ballasting as well as basic marine or technical training. The Canada Oil and Gas Lands Administration (COGLA) requires that ballast control operators on units operating off eastern Canada must have attended an approved course in ballast control for floating units. There are no published standards, however, for their training. The minimum qualifications vary as do the training programs offered by drilling contractors. Their training should include stability of multihull MODUs both intact and damaged, ballasting procedures in the event of damage or loss of the main control system, and an appreciation of the effects of anchor tension on stability and trim. Some instruction on the actual unit's system should also be included. The Watchkeeping Mate Certificate would be a good basis on which to develop these courses.

In Norway, the Chief Engineer is known as Technical Section Leader. In addition to holding a Certificate of Competency, Marine Engineer Officer Class 1 (Machinery or Electro Automation) or Chief Engineer's Certificate, and having at least

one year's experience as Technical Assistant on a MODU, he must undergo an approved course of training for Technical Section Leaders. On U.K. registered vessels, engineers are not required to have specialized training in order to work on a MODU. The level of training required to ensure competency is left to the owner to determine.

MODUs generally have a Chief Engineer on board at all times who is responsible for the operation and maintenance of electrical, mechanical, and lifting equipment. The U.S. Coast Guard issues certificates for Chief Engineers of "column-stabilized or self-elevating mobile self-propelled motor drilling vessels of any horsepower." Candidates for Chief Engineer require four years' service in the operation, construction, or maintenance of diesel engines, and at least two of them should be as oiler, engineer, mechanic, electrician or similar on a suitable MODU. In the United States, most companies train engineers in-house, using on-the-job videos, slide and tape presentations, and packaged courses. Some companies have candidates take a variety of short courses, either in-house or externally.

MODUs of Canadian registry carry engineers who hold conventional merchant vessel First and Second Class Engineering Certificates. There is a general shortage of persons holding a First Class Engineer's Certificate in Canada. There are no special requirements for training and certification of engineers for MODUs. Consideration needs to be given to setting up a course which provides suitably qualified engineers (not necessarily marine) with an understanding of all the requirements of MODU machinery and systems. This could be used as the basis for a MODU Engineer certificate. Current Canadian examination standards for normal First or Second Class marine certificate levels, or their equivalent, appear adequate. The U.S. Coast Guard MODU Engineers examination is of a lower standard, and may not be appropriate in eastern Canada.

In the United States, Norway, and the United Kingdom a Radio Operator Second Class Certificate is the generally accepted qualification for radio operators on MODUs fitted with radio telegraphy and engaged in foreign voyages. It is not unusual, however, for an exemption to be granted since trans-ocean voyages are fairly infrequent for most semisubmersible and jack-up MODUs, and they are usually accompanied by other vessels. Norwegian MODUs must carry two radio operators with Marine Second Class certificates. Training courses for all certificates except the Restricted Radiotelephone are generally between six months and two years long and cover major radio technologies (MF, HF, VHF); most courses are weak in the newer telex, telemetry, and satellite transmission systems. The present Restricted Radiotelephone Operator's Certificate issued in Canada does not indicate a sufficient level of competency to qualify radio operators to work on a MODU unless the employer has provided adequate supplementary training in the operation of specially installed equipment and in emergency procedures. Radio operators with certificates higher than the Restricted Radiotelephone Operator's Certificate are adequately trained to work on MODUs. The earth station endorsement proposed by a Department of Communication/Canadian Coast Guard task force would be beneficial if a MODU is equipped with a satellite communications system.

There is no formal requirement in the United States or the United Kingdom for crane operator training. Industry practice is either to send crane operators to an onshore school, or more commonly to provide on-the-job training under supervision. In Norway, the regulations require that a crane operator must have served on a MODU or platform for six months as a roughneck or roustabout, have completed a training course approved by the Maritime Directorate, and have experience in operating cranes on a MODU under the supervision of a licensed crane operator. Onshore crane operator licences are accepted, but additional training may be required. In Canada, there are no regulations requiring training or certifica-

tion of offshore crane operators, nor are there any specifically organized courses for crane operators; Canadian owners of MODUs currently make use of schools in the United States. Consideration should be given to establishing a facility for realistic offshore crane operator training in eastern Canada.

In the United Kingdom, there are no specific requirements for Helicopter Landing Officer (HLO) training, but most companies use the special two-day course offered by Petroleum Training Association North Sea (PETANS) and Scottish Offshore Training Association (SCOTA). The course has been developed as a result of cooperation between all parties concerned and although it has no official status, it is effectively an "approved course". The training requirements on mobile drilling units in Norwegian waters are essentially the same as those in the United Kingdom. The position of helicopter landing officer is not officially recognized on most units operating off Canada, and is not filled by any particular class of crew member. There are no established courses in the United States or Canada for this position; specific training takes place on the job. In a complex and potentially hazardous situation, the presence of a trained person, able to understand the sequence of events and react to any incident is essential. A committee, comprised of helicopter operators, MODU owners, and government should be set up to consider existing European training courses with a view to requiring similar training in Canada.

Only Norway has the formal requirement of a First Mate's Certificate for Dynamic Positioning (DP) Operators. Additional training is usually provided on the job. Manufacturers offer basic operation courses which are generally attended by DP personnel from new units, who then train their successors on the job. The U.K. Nautical Institute has made a proposal which is under consideration, to the U.K. Department of Transport for formalization of DP Operator training. In Canada, the establishment of a suitable DP Operator course and the provision of simulator facilities should be taken under advisement. This may not be necessary if DP equipment suppliers can provide adequate training. Simulator training is the only practical way to practise emergency actions.

Canada has the only formal requirement for the training of ice and weather observers. They must pass the aeronautical and maritime weather observation examinations of the Atmospheric Environment Service (AES). Companies can arrange their own training with AES approved instructors. Examinations for the Supplementary Aeronautical Weather Observer's qualification are administered by AES staff. Most new observers require eight to ten days to become familiar with meteorological equipment, observation, and standard recording formats. In addition, companies provide about two days' training on company procedures, oceanographic equipment, and observation. For observers on units where icebergs may be expected, the companies arrange additional in-house training on ice plotting. Training in radar observation is provided in-house or through a local training institution. The training of observers appears to be adequate for their tasks, especially where the policy of having new observers accompany experienced personnel for a time is practised.

■ *DRILLING CREW* The composition of the drilling crew is similar for all MODU types regardless of flag. The drilling crew is divided into two "tours", each working twelve-hour shifts. They are supported by various specialist service personnel who are usually directed by a representative of the operator. Only Norway has a comprehensive training scheme for drilling personnel, which is oriented towards offshore operations. Canada and the United Kingdom require blow-out prevention (well-control) training for key drilling personnel; the United States requires it for all drilling personnel. Well-control training is necessary for all key personnel and should include instruction on the subsea blowout preventer (BOP) unless, as in the case of a jack-up, a subsea BOP is not used. Subsea engineers, in particular, need

to be well trained in the use and maintenance of these devices. There are adequate facilities for drilling training in Canada, but there is a need for consultation between government, industry, and the educational sector to make the best use of these facilities to provide specialized offshore training. Reciprocal acceptance of Canadian well-control certification with other countries should be sought. Because of the nomadic nature of the industry, it is a great advantage if drilling personnel can operate in other countries without recertification.

■ *SUPPORT SERVICE CREWS* An offshore drilling program receives logistic, supply, and transportation support from both vessels and aircraft. Offshore support vessels perform a number of specific tasks: they carry supplies and diving support systems, perform anchor handling duties, and tow icebergs. They may also act as the MODU's dedicated standby vessel and are, therefore, fitted with fast rescue craft (FRC) and other basic rescue and emergency equipment. The normal marine training of officers and seamen, while adequate for general performance of their duties, does not cover certain aspects of marine support, particularly the transfer of cargo at sea. To bring confidence to the crews, additional training needs to be provided. For vessels fulfilling a standby role, crew members must have considerable experience at sea but they must also receive rescue and emergency training. Deck hands on vessels performing standby duties are currently inadequately trained in using specialized rescue equipment, new recovery techniques, or handling large numbers of casualties. A course, therefore, needs to be developed which will provide them with a thorough grounding in standby and rescue duties. The FRC crews need specialized training and regular practice, but all crew members must be trained to launch and recover fast rescue craft, to recover survivors from the water, and to give initial treatment for hypothermia. All standby vessel crew members regularly employed on support vessels should have the same level of training in basic safety and survival as MODU crews, including training in the use of specialized lifesaving appliances not covered by MED II. Regular drills and refresher training would be required to ensure they maintain their skills.

Government control of aircraft operation in Canada is extremely stringent with respect to equipment, personnel, and operations. Local offshore helicopters are equipped to carry hoists and other rescue equipment which is held on shore, but crews specially trained in the operation of this rescue equipment are not employed by the helicopter operators. Canadian commercial helicopters could, at least under daylight visual flight rule conditions, conduct SAR operations, if the crew were properly trained. Helicopter underwater escape training (HUET), in-flight cabin firefighting, and first aid need to be considered for flight crew training. Survival and first aid training for flight crew members would also enable them to deal with emergencies while awaiting assistance. HUET as a requirement for passengers should be also considered. At present no formal helicopter rescue training courses exist outside those conducted by the Department of National Defence, although some companies provide their own programs. Consideration needs to be given to the provision of search and rescue technician (SARTECH) training for civilian personnel, if the military SAR capability cannot be developed.

Summary of Offshore Training Seminar

The loss of the *Ocean Ranger* in February 1982, revealed that serious deficiencies existed in the quality of training given to workers employed in Canada's offshore drilling industry. Since that time the industry, government, and training institutions have taken steps to develop and implement a number of programs aimed at improving the level of basic emergency and survival training received by persons working offshore. Similarily, specialized training programs have been developed for persons holding key positions on MODUs. On September 24, 1984, the Royal Commission sponsored a seminar to update its data base on the training programs provided to offshore workers. Representatives from the industry, government, and training institutions participated in the general discussion.

While there was general consensus that basic emergency and survival training is necessary and valuable in preparing workers to cope with emergency conditions and abandonment of MODUs, there was considerable discussion on the timing and amount of training being provided. The operators and the Canadian Petroleum Association (CPA) felt strongly that basic emergency and survival training should not become a prerequisite to offshore employment given that industry is committed to training all offshore workers on a rotation basis and approximately 90 percent of the workers have already completed the training. COGLA supported CPA's suggestion but indicated that the issue of the amount of training required for service personnel and for those working offshore for brief periods of time, has not been resolved. There was general agreement that basic emergency and survival training should be revalidated at appropriate intervals such as every two or three years.

The industry is aiming to achieve a national standard for basic emergency and survival training through and certified by the Petroleum Industry Training Service (PITS). COGLA supports the idea of a national training standard to facilitate the transfer of Canadians within the oil industry in Canada but has reserved decision on its own role in certifying training. COGLA expressed concern about the need for more rigorous blowout control training in light of the recent well-control problems experienced on the *Vinland* and *Zapata Scotian* rigs.

A philosophical difference exists between industry and regulatory agencies as to the level of emergency training required for offshore rig workers. The industry strongly advocates the specialist team training approach to cope with incidents such as fire, well control, and medical emergencies. While COGLA and the Canadian Coast Guard seem to concur with industry, the Newfoundland and Labrador Petroleum Directorate has supported a higher level of training in particular areas for all offshore workers.

The industry indicated that the content of refresher training courses may need to be expanded beyond the scope of current certificate courses for basic emergency and survival training and specialist team training. This concern is under review by the PITS Examination Certification Committee.

A helicopter pilot suggested that aircrews on offshore routes require survival training, and that procedures should be established for rig emergencies occurring during helicopter shut down. The representatives from training institutions indicated that helicopter underwater escape training (HUET) will soon be available to the aircrews. The operators suggested that helideck crew training be made formal through PITS in order to gain recognition and develop standards. A helicopter pilot expressed concern that aircrews are not well trained in search techniques and that the industry search and rescue capabilities could be tasked to assist other industries and the public. The regulatory agencies unanimously indicated that any

assistance rendered to the public using the industry's search and rescue capability would be entirely at the discretion of the helicopter contractors.

The operators feel that they have reached an acceptable level of self-help rescue capability given the available level of search and rescue (SAR) assistance. Independent companies are developing search and rescue training courses and government search and rescue has offered assistance to train civilians. A Newfoundland Government representative expressed the opinion that the current level of air rescue support is inadequate for the offshore and that until additional public resources are made available it is incumbent upon the industry to provide the service.

The Canadian Petroleum Association has recognized the concern of supply/standby vessel masters about emergency and rescue capabilities and has initiated a Senior Officer Marine Emergency Management Forum through PITS. The representatives from training institutions indicated that there is a problem with the current selection method for crews of fast rescue craft (FRC); crews are hand picked by the master of the standby vessel. It was suggested that masters' attendance at FRC courses may improve their crew selection procedures, their understanding of the operational requirements of the FRC, and their enthusiasm for conducting FRC drills. One representative of a training institution suggested that FRC courses should place greater emphasis on transferring casualties to the standby vessel than on recovering the FRC. Another expressed the opinion that a team approach be fostered for FRC crews to include the master's and mate's responsibilities to manoeuvre the standby vessel to pick up the FRC and its occupants. A representative of PITS expressed the opinion that the team approach is best developed at sea during drills. The FRC course was developed in consultation with Coast Guard and other government agencies but is certified by PITS.

There was a general consensus that the MODU marine master requires some knowledge of drilling, and that the toolpusher requires some knowledge of marine matters. The operators and drilling contractors felt strongly that decision-making during an emergency should be carried out as a result of consultation between the master and the toolpusher. Representatives from COGLA and the Coast Guard indicated that the master is always in charge on a semisubmersible.

The Canadian Petroleum Association strongly expressed its desire to maintain the certification processes for drilling activities within the industry where the requisite expertise lies and indicated that only some marine and drilling positions should be certified. The operators indicated that training for dynamic-positioning operators should not be the focus of a regulation due to the relatively low number of these operators worldwide. The operators and drilling contractors have developed a proposal for a Ballast Control Operators' course which is under review by a joint government and industry training committee. The Coast Guard may certify the course content and delivery agencies.

According to training institutions, the present informal mechanism for feedback on equipment performance in training, from the institutions to the designers and manufacturers, is adequate.

The training institutions expressed concern about the lack of a mechanism allowing them input to the identification of training needs and training program development. PITS maintained that industry is responsible for initiating the development of training programs based upon assessments of its training needs and that PITS would seek input from government agencies and the training institutions. The Canadian Petroleum Association perceives standards for safety training to be a

concern of government but job skills training as the responsibility of industry. There were indications that feedback to the training institutions, from industry experiences such as actual abandonment of MODUs has not been adequate, however, industry seemed aware of this deficiency and stated intentions to rectify it.

There appeared to be a consensus that the greatest deficiency in the present organization of training is the lack of time allowed by regulatory agencies for industry to develop, organize, and implement training programs. The drilling contractors stated that the industry had failed to convey effectively the great improvements it has made in training offshore workers. The operators perceive the next step in training to be to refine existing training programs such as FRC courses.

6

HEALTH

HEALTH

OCCUPATIONAL HEALTH AND SAFETY

Occupational Health Study
Centre for Offshore & Remote Medicine
(MEDICOR)
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At present, offshore health and safety jurisdictional and legal matters are more complex in Canada than in the United States, United Kingdom, or Norway. By Acts and Royal Decrees, Norway has developed an extensive and detailed list of regulations covering almost all aspects of health and safety, and involving many government departments and directorates. The regulations specify the right to inspect installations without notice and give inspectors priority rights to the helicopter services of the operator.

In the United States a number of government agencies deal with the offshore oil industry, but the overall responsibility for health care and safety is generally assumed by the operating oil companies. This is particularly true with respect to education, training, and certification of health and safety personnel. There are no common standards or guidelines applicable to the education and training of health and safety personnel or to health care across the petroleum industry. Consequently each company, using its own resources, or those of private medical organizations, provides the level of care it considers appropriate.

The United States, like Norway, spreads responsibility (with significant overlaps) for health and safety matters over more than a half dozen relatively autonomous federal agencies. Furthermore there are differences in health and safety codes between states, and state and federal regulations sometimes conflict. Generally there is much less regulation in the United States than in Norway and the United Kingdom.

In the United Kingdom, responsibility for health, safety, and welfare has been delegated to the operators. Government implements guidelines rather than detailed regulations, and inspection of rigs and installations is arranged at times convenient to the company. There is no requirement to register health professionals working offshore and their education, training, and qualifications are the responsibility of industry. The United Kingdom Offshore Operators Association (UKOOA) has developed standards for health and safety that exceed those suggested by government. The Department of Energy has the prime regulatory responsibility.

Canadian regulatory requirements exist at federal and provincial levels. Enforcement of regulations dealing with health and safety is hindered by the fact that many of the vessels in the offshore operation are foreign registered and standards of health care, training of personnel, equipment, and supplies are based on the regulations of the country of registration. Licensing of all MODUs to a minimum Canadian standard would vastly improve contingency planning and facilitate

health care. Legislation would be required at both federal and provincial government levels to enforce a minimum Canadian standard; alternatively, compliance could be effected under the present licensing system, in which the operating company's medical director would be required to assume full responsibility to meet regulatory standards of health and safety for all workers on the rig including the personnel of contractors and subcontractors.

The emergence of the Canada Oil and Gas Lands Administration (COGLA) as the primary federal regulatory agency could have the advantage of furnishing a "single window", provided that ambiguities and overlapping responsibilities with other federal agencies are resolved. To this end COGLA has initiated consultations at the provincial level, and with the federal Department of Health and Welfare.

In Newfoundland, occupational health and safety matters, in general, fall under the jurisdiction of the Department of Labour and Manpower (Health and Safety Division), the Department of Health, and the Workers' Compensation Board. The Newfoundland and Labrador Petroleum Directorate (NLPD) has responsibility for offshore health and safety. In Nova Scotia, control and regulation are vested in the federal government, while the Workers' Compensation Board, on behalf of government, conducts health and safety inspections and accident prevention training for the offshore and for other industries.

Although registration and licensing of health professionals is an accepted practice, this form of enforcement is hindered by limited jurisdiction offshore. Physicians and nurses working outside the 12-mile limit are not covered by the malpractice insurance policies of their respective professional organizations. They have had to obtain malpractice coverage through private plans because, in attending a patient on a foreign registered installation, they are at risk of suit for malpractice under the laws of the flag country. Non-registered nurses and medics such as the Canadian Armed Forces classification TQ6B medics are not eligible for registration or licensing under current provincial legislation. Therefore, licensing and registration for offshore health personnel should be rationalized. There are practical difficulties in granting recognition to the qualifications of retired TQ6B medics.

In the Canadian oil industry, the executive management roles of physicians have been limited in comparison to those of their counterparts in Norway and the United Kingdom. The rig's medic, who is administratively responsible to the rig manager, may be clinically responsible to doctors from two different companies, the operator and the contractor. Guidelines are required to establish the role of the physician within the company and the relationship between medics and physicians. The operator's medical director should have the final responsibility for all matters affecting health care in an offshore drilling program.

To achieve uniformity of health care and unambiguous regulatory structures, federal and provincial government agencies must develop coordinated approaches. Until recently, there has been relatively little communication between physicians in government and industry. As more expertise in offshore medicine is developed and identified, this deficiency should be corrected and should result in an improved health care system in the offshore.

■ *PREEMPLOYMENT MEDICAL ASSESSMENT* The preemployment medical assessment should establish a worker's medical fitness to perform satisfactorily on the job and in an emergency without risk to himself or his co-workers. It must take into account his capacity to adapt to the harsh environment, the long work schedules, the psychological stresses, and the uncertainty of medical evacuation, or the availability of medical personnel from on shore. A physician, who is familiar with the demands placed on the offshore work force, should conduct preemployment assessments, prior to the worker receiving offshore training courses, since certain parts of these courses are stressful.

In the United Kingdom, the industry (UKOOA) has developed guidelines for

medical standards of fitness for offshore workers. In Norway there are comprehensive preemployment criteria, designated by legislation, for fixed rigs. The medical assessment of workers on MODUs, however, is covered by less stringent regulations. There is also a mechanism whereby a worker can appeal the examining physician's decision regarding medical fitness. In Canada preemployment medical examinations are not standardized. Each operator and contractor develops separate criteria which may vary significantly among companies. The regulatory agencies should be responsible for determining minimal acceptable preemployment criteria for all offshore workers which clearly set out contraindications to employment but leave room for clinical judgement.

There is a growing consensus in the North Sea, as well as in Canada, that a set of common guidelines should be developed to cover regional and national areas. These guidelines will help to facilitate an international standard for medical fitness which can be applied across the industry. While the concept of a medical passport has been examined, particularly in Norway, it has not received much support.

Medical examinations should be conducted with increasing regularity as workers pass 40 years of age and special examinations and assessments are necessary for workers in certain categories, such as diving.

■ *LABOUR FORCE AND WORK ENVIRONMENT* The eastern Canada offshore labour force comprises mainly young, single, or separated males with post-secondary education. Persons within the work force are exposed to a number of health hazards, some unique and others common to industrial workplace environments. A drilling unit's 24-hour work schedule results in a continuous exposure to noise. Noise can be a safety hazard, preventing workers from hearing operating instructions, or causing irritability or inattentiveness which may lead to a higher incidence of accidents. Excessive exposure to high noise levels can lead to industrial deafness. Hydrogen sulphide gas poses a significant health hazard and exposure to drilling fluids may result in skin and eye irritation.

Although major psychiatric disorders and significant neurotic illnesses have been reported on the Canadian East Coast, there are no reliable data from which to assess whether the incidence of these conditions is higher among workers in the offshore than among comparable groups in conventional settings. A worker's personal instability or over-reaction to stress is a matter of both health and safety. The expectation is that someone with difficulties in coping with stress in everyday situations will be unable to respond to super-added stress and may become a liability due to impaired efficiency. As in the North Sea, alcoholism is the predominant major psychiatric disorder observed in offshore workers on the Canadian East Coast. The data on the incidence of sleep disorders are inconclusive.

The preemployment medical assessment should identify those workers who have demonstrated adverse reactions to stress or who have suffered from psychiatric disorders. Reliable data are required on the adverse effects of noise, exposure to hydrocarbons, and stress associated with the offshore environment.

■ *INCIDENCE OF ILLNESSES* Because of the nature of the work force employed offshore eastern Canada and screening by preemployment assessment, the number of cases of serious illness is likely to be low. The majority of illnesses offshore can be diagnosed and treated by the medic on the drill unit without supervision by a shore-based physician. For the less frequent, severe disorders, individuals are evacuated to onshore medical facilities.

An analysis of a medical log from a MODU operating on the Canadian East Coast showed that illnesses were four times more frequent than accidents but were usually less severe and did not require evacuation or consultation with the onshore supervisory physician. The majority of illnesses were mild upper respiratory tract infections, headaches, and mild skin disorders. These types of illnesses are

similar to those reported in other offshore jurisdictions.

■ *ACCIDENT DATA COLLECTION* The collection of personal injury data is essential to determine the health status and safety performance of offshore workers. The use of available accident data is, however, limited. Different criteria are used to define serious and minor injuries and the reporting of incidents is unreliable. Unreliability in accident data can occur when a "safety-bonus" system operates. Accepting the limitations of the data collection methods, statistics should be collected to determine the incidence and also the cause of all offshore accidents.

Accidents arise not only from deficiencies in equipment and facilities but from characteristics of the worker: lack of experience, lack of knowledge of the correct procedures, carelessness, clumsiness, or failure to wear protective clothing. The coordinated efforts of a team are required in most procedures on the drill units. The team may be composed of individuals who differ greatly in their levels of skill and experience and accidents may arise when the team's coordination is lost. An employee must, in the final analysis, be motivated to take responsibility for his own safety.

Many studies have been conducted on the time relationships of accidents to shift and hitch, but the evidence is inconclusive. Approximately 20 percent of the work force will be unable to tolerate rotating shifts but these individuals will be self-screening. The incidence of accidents is highest among employees new to the job. In some offshore operations, the turnover of junior drilling crew positions is 100 percent. This situation entails new learning experiences and a new period of vulnerability to accidents.

An analysis of accident rates on drilling units operating off Newfoundland and Labrador indicated that minor accidents were 12 times more frequent than major accidents. Hand and wrist injuries were the most common, resulting from "being struck". Major accidents affected roustabouts, roughnecks, and drillers, and the most commonly reported nature of these was contusion. These findings agree with reports from other jurisdictions.

A more detailed profile of the health of offshore workers is required and a properly designed system of data collection should be instituted which will permit meaningful comparisons with foreign petroleum offshore operations and with onshore Canadian industries.

■ *HEALTH CARE RESOURCES OFFSHORE* Although individual medics and physicians will have personal preferences, the medical equipment and supplies for the sick bay on the MODU should be standardized to aid contingency planning. The equipment should be clearly identified for use by the medic, the physician, or the medical emergency response team. Regulatory agencies should assume the responsibility for framing minimum standards for medical equipment and supplies on board any unit licensed to operate on the Canadian East Coast. This standard should be based upon the number and type of reasonably anticipated casualties, even though these numbers are difficult to estimate.

Medical input is required in determining the design, layout, and equipment of health facilities on drill rigs. The safety and efficacy of X-ray machines offshore is highly dependent on the training of those who will use them and there is currently no concensus as to their need. An ECG monitor and a defibrillator may be provided if the medic is trained to use them properly.

Major factors affecting survival in lifeboats are injuries sustained during abandonment: trauma, hypothermia, thirst, motion sickness, exhaustion, and hunger, as well as general morale. Current Canadian Coast Guard requirements for medical supplies and equipment for lifeboats and life rafts need to be modernized. A motion sickness prophylaxis should be added to the medical supplies in lifeboats and life rafts. Further, drug dosages should be expressed in milligrams rather than grains. Current scales of provisions such as water and food on lifeboats appear to

be satisfactory. Improvements are required in the design of survival suits.

■ *HEALTH PERSONNEL QUALIFICATIONS* The rig medic may work in lieu of a physician or as an extension of a shore-based company doctor. The duties range from conducting a routine sick parade to handling multiple casualties. Under certain circumstances, a patient may have to be cared for over a long period. In emergencies, the rig medic should be supported by a competent team trained in advanced first aid. A wide range of knowledge and skill is required for the medic including:

- Basic knowledge of anatomy, physiology, pharmacology and pathology;
- Thorough competence in the basic skills of history-taking and physical examination of all body systems;
- Diagnosis and communication of findings in a rational, problem-oriented manner to a physician;
- A broad working knowledge of pharmacology;
- Resuscitation of the seriously ill or injured casualty involving competence in cardiac life support, airway management, hemorrhage, and shock;
- Thorough understanding of the pathophysiology of drowning and hypothermia and their management;
- Understanding the concepts of public health and industrial hygiene and the control of infectious diseases;
- Some surgical skills;
- The ability to faciliate communication between the diving team and a shore-based physician and to advise the diving supervisor intelligently;
- Counselling skills and psychiatric knowledge.

While the medic may be given other duties, these should not conflict with medical duties. Because of the organizational structure within the company and its contractors, conflicts of responsibility may arise.

The obligation of confidentiality and privilege in the patient/physician relationship similarly applies to the medic/patient relationship and may result in a conflict for medics as they are employees of the drilling contractor. Medics' conflicts may be enhanced by the dichotomy in their responsibilities to the toolpusher or master for administrative matters and the supervising physician for clinical, professional matters.

A breach in patient's confidence through the disclosure of medical records should be precluded by maintaining them as confidential between the medic and the patient. If an employee discloses a medical problem which casts doubt on his fitness for employment or which entails a danger to himself and others, the medic's duty is clearly to counsel the employee to resign. If the employee refuses to resign, the medic must report the matter to the employer who may terminate the employment. It requires maturity of judgement gained through experience to successfully manage the dichotomy in professional and administrative responsibilities. This need for maturity of judgement, as well as the technical requirements of broad experience in the practical management of medical problems, may make newly qualified physicians less suitable for the post of rig medic than experienced nurses or TQ6Bs.

The qualifications of rig medics vary in different areas of the world. In the United States, they vary from company to company. The most common categories of personnel hired as medics are ex-military medics (paramedics), emergency medical technicians (who will have undertaken training programs of varying length, up to two years), and persons with first aid qualifications. Since the drilling units in the United States are closer to shore than in other offshore areas and regular helicopter transport is available, there are indications that these qualifications are adequate.

In the United Kingdom, legislation is being enacted which allows only ex-military, independent-duty Medical Assistant I's or State Registered Nurses to be employed as offshore medics. At present, in Canada, retired Canadian military TQ6A and TQ6B medics, registered nurses, retired U.S. Armed Forces military technicans, and emergency medical technicians are employed as rig medics on offshore drilling units. Federal and provincial regulations would allow a provincially certified first aid person to be hired as a rig medic. There is, however, also a federal guideline which requires that the rig medic be able to perform a number of specific functions which are beyond the skills of such a person. This conflict within offical regulations and guidelines illustrates the need for expert medical input into such regulations. The registered nurse and the Canadian military TQ6B are highly suitable for employment as rig medics on the basis of the requisite training for their qualifications. The emergency medical technician's training is considered to provide an inadequate background for the performance of the offshore rig medic's duties. If possible, a mechanism should be found to allow professional recognition for the position of ex-military medics (TQ6B). The lack of such a mechanism causes medico-legal difficulties which do not affect the registered nurse. All offshore health personnel including physicians and medics will require some training before taking up duties. For physicians, some 80 hours of instruction would be required and a 6-month course would be required for medics. This period of time would be reduced by instituting a modular course in which the training could be tailored to the needs of the individual nurse or ex-military medic. Continuing education courses should be conducted at regular intervals by appropriate educational institutions to ensure that infrequently used skills are updated.

■ *FIRST AID TRAINING FOR WORKERS* Basic first aid training is advocated for all offshore workers. First aid courses for all workers should include instruction in safety-oriented first aid, with expanded modules on hypothermia and near-drowning. Cardiopulmonary resuscitation and hydrogen sulphide courses should also be taken. As sections of conventional first aid courses may not be suitable, regulatory agencies should assume responsibility for approving course content, monitoring the examination procedures and certifying the adequacy of the instruction to be offered. To avoid decline or loss of skills, refresher courses should be taken regularly.

Each drilling unit should have an advanced first aid team to provide first aid coverage in the lifeboats during evacuation, assist the medic in triage and care of patients with multiple injuries, and escort patients to shore.

The medic should be responsible for conducting first aid drills and providing instruction to the team on topics such as transportation of the patient, resuscitation, and the use of the sick bay equipment. A record of drills should be maintained. The members of the advance first aid team should not have conflicting emergency duties.

■ *COMMUNICATIONS AND TRANSPORTATION* Because of the crucial importance of communications in a medical emergency, reliable systems must be devised and tested. Communication with other parts of the rig and with onshore bases should be possible from the sick bay. In addition, an exclusive line should be available for the sick bay telephone.

Early results of a pilot project by Memorial University of Newfoundland, federal Department of Communications, Newfoundland Telephone Company, and Mobil Oil using the 14 and 12 gHz Anik B satellite system indicate that telemedicine techniques, (transmission of slow scan pictures and electrocardiograms), can enhance significantly the ability of an onshore physician to advise the medic. Satellite technology may provide cost-effective alternatives to existing communications systems.

Despite noise and vibration, cramped conditions, the effects of high altitude

on a patient, and weather restrictions, medical evacuation by helicopter is preferable to evacuation by sea. Evacuating a patient by air requires an escort, and planning is required to accommodate support equipment.

■ *DIVING* The Canadian Standards Association (CSA) and COGLA have recently produced a standard and draft regulations, respectively, which reflect modern diving practice. In a few areas there are inconsistencies between the standard and the draft regulations. While they compare favourably with those of other countries, the COGLA draft regulations do not address surface decompression diving and the training of life support technicians is addressed only briefly.

Company contingency plans should cover evacuation of divers who are in saturation, in the event of abandonment of the MODU, and they should ensure that rescue operations can be undertaken from a diving bell trapped on the sea bottom.

Communications required for diving operations are vital in an emergency. When treatment is conducted in a compression chamber, it is desirable that the person making the decisions be outside the chamber with clear communication links to the person inside conducting the procedures. The diving station should also have direct reliable communications to shore, preferably using a satellite link.

Diving accidents have occurred when diving was undertaken from dynamically-positioned vessels. This mode of diving should be the subject of ongoing scrutiny. Research into and development of techniques is required to extend the diver's survival time if the surface gas supply should fail, particularly in deep diving.

Treating a sick or injured diver can be a complex operation. Days may be required to bring a diver in saturation to surface pressure and hours to compress an attendant to enter the chamber to render aid. All divers should be trained to a high standard of first aid, including training in the first aid of diving emergencies. Neither the rig medic nor the diving superintendent can attend the patient in the chamber, therefore diving teams should include divers who have been trained as diver/medical technicans to render immediate medical care.

In an offshore diving accident the priorities are to recover the diver into the on-site recompression chamber and then to initiate treatment through consultation with medical expertise on shore. In some instances, the diving specialist physician may travel offshore, possibly with members of the Medical Emergency Response Team, taking necessary monitoring supplies and other equipment. If transfer of the diver-patient to a shore-based facility is contemplated, the patient should first be stabilized in the offshore chamber and a rescue system involving a "fly-away" chamber could be utilized.

Evacuating an installation because of weather or danger of iceberg collision presents problems for divers in saturation. Possible methods include transfer to a support vessel, using a "fly-away" hyperbaric chamber or a hyperbaric lifeboat. Neither a "fly-away" hyperbaric chamber nor a hyperbaric lifeboat is available in eastern Canada. There is a need for an adequate onshore hyperbaric medical facility in Newfoundland. Technical problems of using these systems individually or in combination have to be solved.

Special training in hyperbaric medicine is advocated for diver medical technicians, life support technicians, diving supervisors, medics, and physicians. Because diver medical technicians are not recognized in Canada, there can be medico-legal problems. Recognition could be granted if training were given under the Canadian Medical Association's (CMA) Emergency Medical Attendant program.

Diving supervisors should be familiar with the concepts of diving medicine and physiology in addition to their knowledge of operational diving procedures. Physicians should be specially trained to conduct medical examinations for fitness to dive and some should be trained as specialists in diving medicine. Such courses

are not readily available in Canada. Refresher courses could be held for specialists already trained.

Research needs identified in diving medicine and physiology include the development of improved "bail-out" gas supply systems for deep diving, the physiology and pathophysiology of decompression sickness, thermal protection, and oxygen toxicity.

■ *ONSHORE MEDICAL RESOURCES* The oil companies and drilling contractors operating on the Canadian East Coast have contracted groups of local physicians to provide medical advice or assistance to offshore medics on a 24-hour basis. In a medical emergency offshore Newfoundland, the physician may choose to attend himself or to call upon the General Hospital's Medical Emergency Response Team, comprised of specialist physicians, nurses, and support technicians. This team takes along specialized medical equipment which allows them to provide initial resuscitation under adverse conditions. The team will return the patient to a hospital designated by the team leader based upon the type of speciality service required by the patient. Formal designation of a Medical Emergency Response Team to respond to offshore and onshore emergencies should be considered in Nova Scotia and a formal procedure for air evacuations should be established for the Venture field.

Public health physicians should be trained in offshore health care and involved at all levels of offshore operations to ensure that the interests of workers, industry, and government are served by a cooperative approach between the appropriate federal and provincial government departments.

■ *CONTINGENCY PLANNING* When an emergency occurs, there must be a contingency plan in place to ensure that the patient is provided with the best care at every stage of management, from immediate first aid to eventual treatment in a land-based facility such as an intensive care unit. The operator can cope with the majority of problems using his own resources, but on occasion will require assistance from other sources. The contingency plans generally do not delineate clearly the lines of responsibility and relationships between rig medics, physicians, and administrators.

COGLA delegates the responsibility for emergency health care to the provincial agencies and has developed standards for the contingency plans submitted by companies, which require that the roles of key personnel be defined. The Newfoundland and Labrador Petroleum Directorate assumes the coordinating role in an emergency, but clarification of the relationships with other agencies is needed.

As a result of meetings between representatives of the various agencies involved in offshore emergency health services, consensus was reached about the general procedures to be followed. Some uncertainties exist about the roles of certain agencies. To reduce these uncertainties and to provide continuity, a standing liaison committee is proposed with a range of functions from reviewing collectively the emergency response capability of each organization to facilitating disaster exercises.

[Editor's Note: The Canada Oil and Gas Lands Administration Drilling Guidelines and Procedures *(September, 1984) indicate that the requirements for rig medic qualifications are under review but for the present the operator must present a statement by a qualified physician that he has reviewed the qualifications of each medic and found them to be satisfactory. The minimum standards are: registered nurse with a minimum of two years' experience with emphasis in intensive care or emergency; or formal paramedical training at the college level with three years clinical experience; or a recent military paramedic qualification to Grade VIB. Potential medics must hold a current registration with an appropriate professional licensing authority.]*

Summary of Occupational Health Seminar

In February 1984, the Centre for Offshore Remote Medicine (MEDICOR) of the Faculty of Medicine, Memorial University of Newfoundland, submitted a report on Occupational Health and Safety to the Royal Commission. The Commissioners encouraged the establishment of a seminar at which the content of the report could be discussed by a number of invited experts. On June 26 and 27, 1984, participants from industry, government, training organizations, and health institutions attended this seminar.

At the outset, Dr. A.M. House, Director of MEDICOR, identified some of the current occupational health issues affecting the organization and operations of the Canadian East Coast offshore industry. The lines of responsibility from the operator's Medical Director to the contractor, diving companies and other subcontractors, and to standby and supply vessels, need to be identified and carefully considered to ensure that the operator's responsibility for health services is being properly discharged. For example, the current practice of hiring rig medics through subcontractors impedes clear and efficient lines of administrative and clinical authority between the operator's Medical Director, who is ultimately responsible for provision of health services, and the medic, who provides daily on-site health care services. In addition, some categories of medics such as retired Canadian Armed Forces Medics (TQ6B) lack professional status as they are not registered or licensed by a recognized health association. This has serious implications for physicians' professional relationships with these medics.

In general, it was agreed that onshore medical resources in Newfoundland and Nova Scotia are adequate to cope with the emergency health problems which develop offshore and that contingency plans are being improved; there is a need, however, for regular exercises to test the effectiveness of these plans. The Telemedicine Project at Memorial University of Newfoundland has demonstrated that the use of satellite voice communication links and slow scan T.V. can enhance the shore-based medical support available to rig medics and improve communications for general purposes.

Increasing attention is being focussed on educational and training programs for contract physicians and rig medics as a result of improved communications between various government agencies and the medical profession through Advisory Committees. Recent trends in industry recruitment practices reflect acceptance of the recommendation of the *Occupational Health Study* that the registered nurse qualification is the most appropriate for the position of rig medic. There was agreement that the work experience of the registered nurse would influence the length and type of additional training required to perform competently in that position. Furthermore, there was a consensus that primary physicians providing service to the offshore should, besides having Advanced Cardiac Life Support and Advanced Trauma Life Support training and an orientation to the offshore working environment and job tasks, have some expertise in occupational health or have a background in emergency medicine. Further, hospital-based specialists and newly graduated physicians are not suitably qualified for this position.

There was a consensus that the sick bays of some MODUs, operating on the Canadian East Coast, are not optimally positioned to facilitate easy access by stretcher cases or access to the helideck. There is a need to identify a mechanism which allows medical professionals to advise rig designers on the location and layout of sick bay facilities.

Discussion followed on the psychological stress of working and living on a MODU. Although stress factors in the offshore have received a lot of attention,

they are not as significant as is generally perceived. The assertion was made that several individuals with a medical history of major psychiatric disorders have gained employment on MODUs. A preemployment assessment for psychiatric illness is important, and it was suggested that training for supervisory personnel should emphasize the necessity of identifying individuals displaying abnormal behaviour for the safety and protection of that individual and the crew, although the difficulty of making this identification was recognized. It was further agreed that major psychiatric disorders be considered contraindications for offshore employment. There were indications of inadequate preemployment screening of subcontractor's personnel resulting in medevacs that could have been avoided.

Although there is a lack of comprehensive accident data for the Canadian East Coast offshore operations, it was agreed that the injury and illness data analysis presented in the *Occupational Health Study* provided valuable information for industry health professionals. A government health professional recognized that the lack of appropriate occupational health data is not peculiar to the offshore oil industry but rather is characteristic of the field of Occupational Medicine. There was a consensus that reliable data are required, preferably in a form allowing comparison with accident data from other jurisdictions. There was a tacit assumption that a standardized data collection system would be undertaken by government or some central agency involving all the companies, with due consideration given to the issue of confidentiality. Industry representatives emphatically stated that, to elicit their full cooperation in a central data collection system, it must be demonstrated that the system's objectives are clearly defined and the resulting data will be reliable and valid. Drawing upon the experience of other occupational health data collection projects, a government representative suggested that there is a need to develop a uniform job dictionary and to collect data on near misses. It was suggested that to ensure the credibility of a data collection pilot project, a two- or three-year life span would be required. One participant suggested that the Loss Management Information System (LOMIS) already collects the occupational health and safety data being discussed.

It was unanimously accepted that the operator is responsible for the health and safety of all personnel on a MODU. The rig medic, however, is either an employee of the drilling contractor or a subcontractor who may report to the contractor's or subcontractor's physician rather than to the operator's physician. This creates a confusing and potentially hazardous situation. The operator may not be able to discharge his responsibility for the health services provided offshore, as they may not be conducted in accordance with the operator's policy or through the physician delegated the authority to act on the operator's behalf. In addition to requiring contractors to meet the specified health and safety standards, the operator must exercise "due diligence" by monitoring and auditing the contractor's performance in order to discharge reasonably his responsibility for the health and safety of all personnel.

It has been noted that problems also arise between the corporate and operations occupational health and safety groups because the corporate group sets company policy and procedures, and also monitors and audits the operations group's activities. Although management organizations differ, it is common for the communication and coordination between separate safety and health departments to be inadequate. It was suggested that ideally health and safety should be integrated. The roles of industrial hygienists and safety engineers in offshore operations were discussed. One safety representative indicated that in current practice

the term "safety" is being replaced by "risk management" which is concerned with identifying the most efficient and correct method for performing a task. Company management should be committed to identifying and, where possible, eliminating or mitigating risks to employees by developing standards of design, construction, operation, and training which are applicable to all circumstances.

There was general consensus that methods of dry evacuation from MODUs are preferable to evacuation by sea and that research should be conducted in this area. The industry's use of state-of-the-art rescue equipment was discussed. A lengthy debate ensued regarding rapid versus slow rewarming of hypothermia victims. This issue was not resolved, but it was emphasized that standby vessel crews could only be expected to practice first aid and not medicine.

7

ESCAPE AND SURVIVAL

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ESCAPE AND SURVIVAL SYSTEMS

Assessment of the Means for Escape and Survival in Offshore Exploration Drilling Operations
Hollobone, Hibbert & Associates Limited
London, England
June 1984

Semisubmersible drilling units may have to be abandoned as a consequence of: structural failure resulting from design faults; collision; stability loss as a result of incorrect ballasting or loading; and fire or unignited gases caused by a blow-out. Jack-up rigs may be evacuated for similar reasons or as a result of punch-through. Drill ships face the same hazards as semisubmersibles except that they are normally manned by seamen who may be better able to handle marine emergencies than are other rig workers. Supply vessels face the normal problems of any seagoing vessel plus added stability problems because much of their cargo is transferred at sea. In addition, their frequent proximity to drilling units and other offshore structures increases the danger of collision, and their low freeboard aft makes them prone to damage from breaking seas. Helicopters can either crash in an uncontrolled manner with little chance of survival for those on board, or ditch under some control and with some chance of survival.

■ *ABANDONMENT CRITERIA* The most important factors affecting the success of abandonment systems off the East Coast of Canada are environmental and mechanical; therefore criteria have been developed based on historical data to define conditions under which abandonment systems must operate.

Severe storms off the East Coast of Canada typically include: icing conditions; maximum wind speeds of 70 knots; maximum wave heights of 17 metres; minimum air temperatures of $-20°C$; sea temperatures of $-1.8°C$; and visibility of less than 1 kilometre up to 45 percent of the time. Gales could last for up to 48 hours and storms for up to 15 hours. Burning oil or gas and unignited gas from blow-outs can introduce additional hazards.

From a mechanical point of view, abandonment may occur from a MODU with a list of up to 40° and from the following deck heights: supply ships, 5 metres; drill ships, 7 metres; jack-ups, 3 metres in transit and 20 metres on site; and semisubmersibles, 35 metres in transit and 15 metres in the drilling mode. For helicopter abandonment, the exit doors may be as much as 1 metre above or below the sea surface during evacuation.

When considering the type, number, and distribution of abandonment systems, it should be assumed that certain areas of the unit will be unavailable for use because of damage or angle of inclination. Successful abandonment should, therefore, be possible without use of two adjacent sides of a semisubmersible or jack-up; one side or the complete forward, aft or midships section of a drill ship; and one side of a supply vessel or helicopter.

Abandonment systems must be capable of ensuring safe transit of survivors

from the point of entry into them to a position clear of the parent unit. Precedent has shown that a number of existing systems cannot meet this criterion. The most common problems involve the survival craft striking structural members of the parent unit because of the angle of launch, high winds or seas, or incorrectly working equipment such as release gears and survival craft engines.

According to Canadian regulations, abandonment systems must allow for twice the number of people on the unit including ten percent stretcher cases in a combination of lifeboats and life rafts. The total time taken to abandon vessels, including mustering and preparing equipment should not exceed 20 minutes for MODUs; 30 seconds for supply ships providing that preparatory measures are taken early where capsize is deemed to be a threat, (20 minutes otherwise); and 3 minutes for helicopters. Abandonment must be possible without relying on the power supplies of the parent unit, and the operation of the system must be simple and reliable, with suitably trained people in control. Communication links should exist between the parent unit control room, each abandonment post, and, where applicable, each escape craft, and receiving unit.

■ *SURVIVAL CRITERIA* Once a vessel or installation has been abandoned successfully, the emphasis switches to survival. A person's chances of survival in the sea off eastern Canada is most threatened by drowning, which results from insufficient buoyancy and protection, possibly aggravated by lack of bodily control through injury or, most likely, cold. Cold causes hypothermia; as the body core temperature drops, a person's ability for self-help is gradually diminished until death occurs at around 26°C. If a person is to survive, core temperature must not be allowed to drop below 35°C or, at worst, 33°C. The actual water temperature between about 5°C and −1.8°C is not as important a factor as the person's mass to surface area ratio, the amount of subcutaneous fat, general physical fitness, and mental state. Considering feasible response times for vessels or helicopters, rescue from the water should be possible within four hours. It is necessary then for survival suits to ensure that core temperatures of survivors are prevented from falling at a rate of more than 0.5°C per hour. Other physiological effects of exposure to cold air and immersion in water are cold shock, freezing and non-freezing cold injuries, cold incapacitation, sea sicknesses, and loss of body fluid. Suffocation, heart damage, burns, and injuries from excessive acceleration may also pose risks in some abandonment situations and survival systems should take these risks into account.

There are five main types of abandonment and survival systems in current use. These include: evacuation by helicopter, dry transfer, rigid survival craft, inflatable survival craft, and individual abandonment devices (survival suits and life jackets).

■ *HELICOPTER EVACUATION* Helicopter evacuation provides the most satisfactory first line means of abandoning MODUs and offshore platforms since it keeps survivors warm and dry during transfer. This method is only possible, however, if sufficient response time is available (up to four hours); if the units are not listing beyond the limits of the helicopters involved; if wind speeds permit start-up; if fire or gas are not hazards; and, perhaps most limiting of all, if visibility is sufficient.

The rescue capabilities of helicopters vary with different machines. Range, speed, and capacity are all important characteristics. Range and capacity are currently best provided by the Chinook helicopter, and, in the more remote areas of eastern Canadian waters, this may be the only helicopter capable of providing suitable evacuation facilities. The Chinook can tolerate greater pitch and roll because of its two overlapping rotors, and its payload of at least eighty people means that evacuation of a MODU can be effected in a single trip. The capacity of the Bell 212 is eighteen; the Super Puma, twenty-four; and the Sikorsky S-61, forty-four.

There are serious environmental limitations to helicopter operation. Wind speed affects start-up and the time taken to transit against strong headwinds. Start-up for most helicopters, including the Chinook, is only possible up to a wind speed gusting to 50 knots; 70 knot winds are not unusual during storms off eastern Canada. Start-up in normally excessive conditions may be possible if a lee can be provided. Another major limitation is visibility. Cloud ceilings and horizontal visibility below the operational requirements of most helicopters occur in some areas and some months as often as 33 percent of the time. In the North Sea, equipment exists and is in use in military aircraft and commercial aircraft on search and rescue contract which allows helicopters to fly in conditions of virtually zero visibility. These new developments using infra-red imaging systems provide for greatly enhanced capabilities over those available with visual flying or standard instruments.

Helicopters cannot meet the time criteria specified for abandonment, and so can only be used if there is considerable advance warning of an impending emergency. If survivors are already in the sea when a helicopter arrives, or if they are being rescued from a supply vessel or an escape craft, the normal method of recovery is winching. A well trained helicopter crew including a winchman can winch about one person in three minutes in normal conditions, or one person in five minutes in difficult conditions. The speed and number of persons recovered can be improved considerably by using an Emergency Multiple Person Rescue Apparatus (EMPRA) basket or Bennex net. Training is important; a person who has lost body fluid could die unless he is winched in the proper foetal position.

■ *DRY TRANSFER* Dry transfer systems are methods of abandoning offshore installations without having survivors enter the sea. Several different systems have been designed, although many of them only to the conceptual stage. Some have been developed to prototype stage. None have so far been fitted commercially to offshore installations. One main type of dry transfer system is based on the idea of a rigid bridge which can be passed from an installation to a rescue vessel. In view of its size and weight and the need to have a large dedicated vessel to receive evacuees, this concept appears more attractive for fixed installations than for MODUs.

The second approach is based on "replenishment at sea" systems used by many navies. A prototype has been developed in the United Kingdom and ordered for use on board a fixed production platform in the Norwegian sector. This system employs a wire in tension which is sent to a receiving vessel by means of a pneumatic gun. Escape capsules with an eighteen-person capacity are then propelled along the line to the rescue vessel. Computer control of line tensions and potential oscillation and swing-mounted docking platforms which operate within a 150° arc are improvements over earlier dry transfer designs. Among the system's advantages are that it keeps the survivors dry and allows for stretcher cases; it uses power from the receiving vessel; it operates successfully from deck heights exceeding 35 metres and in any sea state; and it automatically propels survivors clear of the parent unit and directly onto a safe haven. The total time to set up the equipment is about 25 minutes and the time taken to transfer 1 capsule is 4 minutes. Thus a MODU containing 90 people could be evacuated in about 1 hour, assuming that the receiving vessel was in close proximity to the MODU when the decision to abandon was made. Although 1 hour exceeds the criteria, it would prove a satisfactory response time in many instances.

The main disadvantage of this system is the cost of providing a dedicated receiving vessel outfitted with sophisticated electronic components and maintaining it within close range of the MODU or offshore structure. For this reason dry transfer systems will probably be limited to permanent installations or clustered groups of MODUs. Another limitation of the system is visibility; those firing the line must be able to see the receiving vessel without that vessel coming dangerously

close to the installation. This situation could be improved with the further development of positioning systems. Dry transfer would also be inoperable in areas of burning oil, although this should not be a problem since transmitting stations would normally be fitted on all four corners of a platform and the line could be sent from any one. This distribution also means that the system could operate even when the unit in distress is listing severely. Overall assessments suggest that dry transfer systems offer good potential for providing a safe evacuation system for use offshore.

■ *RIGID SURVIVAL CRAFT* Rigid survival craft derive from traditional ships' lifeboats. The type fitted in MODUs are generally Totally Enclosed Motor-Propelled Survival Craft (TEMPSC) which are either boat-shaped and launched from twin fall davits or disk-shaped and launched from single fall davits. A third type, currently in very limited use, is the free fall lifeboat which is dropped into the sea. Conceptual designs also exist for several types of underwater-launched survival craft.

Twin fall gravity davits mounted on MODUs either follow conventional ship design or, more often, utilize rigid davit outriggers anchored to the structure of the unit. The escape craft is lowered by gravity with speed controlled from inside the TEMPSC by a brake. This type of launching mechanism can accommodate any deck height and is quick and easy to operate; maximum escape time for 44 people in a 50-person craft ranges from 2 to 10 minutes. High winds can affect the launching and model tests have shown that a nearly empty TEMPSC can swing as much as 4.4 metres from the perpendicular during launch from davits at a 20 metre deck height. High seas can also prove problematic as they can carry the craft under the decks of column supported MODUs, and exert considerable slam forces on the hull of the TEMPSC at the moment of impact during launch. Although no quantitative information exists to predict maximum wind speeds and wave heights that can be tolerated by TEMPSC launched by twin fall davits, estimates are that a boat could be set back 12 metres on release in a force 7 wind and over, and capsized if beam on to breaking seas of over 8.1 metres. Even if the TEMPSC does land in the water safely, it must be immediately propelled away from the structure, and experience has shown that the motors do not always work. Precedents also exist for mechanical failures in brake operating mechanisms and release gears, particularly during icing conditions. It is possible to minimize icing problems by heating winch motors and brakes and using low temperature steel on all main structural members of the launching system, but these precautions have not been built into the design of existing MODUs.

Single fall gravity davits have the advantage of a simpler mechanism with only one place for disengagement and thus fewer chances of failure. The disc-shaped TEMPSC that are generally used with this type of launching mechanism can head in any direction after entering the water, so the problem of a boat-shaped craft entering the sea beam on and possibly capsizing are lessened. The main disadvantage is that the single fall allows greater movement, particularly rotation of the TEMPSC while it is being lowered which can lead to problems both during launch and in clearing the parent structure.

Research into methods of ensuring that TEMPSC launched by conventional single and twin fall davits are not swept into the structure of MODUs in high sea and wind states has led to the development of the PROD (Preferred Orientation and Displacement) concept. This system uses a tag-line under tension attached to the bow of the craft to pull it clear of the structure during launch. The craft then continues to move forward under its own power and the tag-line connection automatically disengages. This system is still under development but appears to offer a possible modification to existing systems which will improve their performance.

Some existing twin fall launching systems use guide wires running from the

davits to either submerged parts of the parent unit or to points on the seabed to steady the TEMPSC during launch and to ensure that it clears obstructions whatever the attitude of the parent unit. It is understood that on several units the use of guide-wires has been discontinued because of the difficulty of reattaching the TEMPSC to the wires after evacuation drills.

Most boat-shaped TEMPSC are currently fitted with off-load disengaging gear; before the boat gear can be operated, the load must be off the falls. This gear has been proven in practice to be unreliable in rough sea states. On-load disengaging gear is fitted in most disc-shaped TEMPSC. Although it does not suffer from the same releasing problems as off-load gear, and is generally considered more reliable, the fact that it is designed to be operated on-load means that it is possible to operate the release mechanism when the craft is still well above the water, a circumstance which led to fatalities in at least one evacuation attempt.

Free fall systems have been under development in Norway since 1973, where two main concepts have been considered. The first involves a skid system where the craft is released down an inclined chute or skid, whereas the second is a true vertical free fall device. Both systems can launch a 13-metre, 60-man craft from a deck height of 26 to 39 metres. The skid system has been fitted in a number of vessels, whereas the vertical fall system has been installed on one MODU and is on order for a North Sea production platform.

One of the principal objectives of the free fall concept is to use the kinetic energy of the craft, built up during its fall, to carry it clear of the structure. Model tests have shown that using the worst angle of impact with 9 metre waves, the TEMPSC cleared the drop point by about 2 boat lengths. The response time for free fall systems is very short; embarkation by 69 people has been achieved in less than 3 minutes. The system is extremely simple to operate and should not be affected by wind speed. Operating success has not been determined in waves of over 9 metres or in icing conditions, but these circumstances are not expected to pose serious problems.

A combined gravity/free fall launch system is under development using the approach employed in many warship applications where the boat is lowered to just above the crest of the waves and then dropped onto a crest. This technique is used in the ''Lifescape'' system, a capsule designed to provide a safe haven for survivors on the deck of the parent unit and to be launched only as a last resort. The boat is suspended in a gravity release davit, carried 10 to 12 metres clear of the parent structure, and lowered until initial contact is made with the water. It can then be released from within the craft to fall into the water. This system can be used from any deck height and test analyses have given favourable results in terms of design characteristics. The rigid construction of the launch system, for example, makes it resistent to high winds. However, the system may not be capable of accommodating lists of greater than 17 degrees or wave heights in excess of 12 metres and may need modifications to operate in very low temperatures and icing conditions. Despite these possible limitations, the ''Lifescape'' system shows promise.

Several versions of a system similar to that designed for launching the ''Lifescape'' but without the final free fall have been devised using rigid booms. One such system was found in model tests to launch a TEMPSC clear of the parent structure in 17 metre waves, but the design is considered of limited applicability because of the weight and cost of components.

A TEMPSC may capsize in waves higher than eight metres, but is designed to be self-righting providing survivors are properly strapped in and there is no damage to the craft. The new *SOLAS Convention* which does not apply to MODUs requires any lifeboats which do not right themselves to have an above water escape route for those inside to climb out. Craft which meet this regulation will

marginally improve chances of survival if they are flooded internally though only if rescue is close at hand. Present TEMPSC are warmed internally, only by the heat of the engine which would probably not be running at all times while awaiting rescue. Accordingly it is possible that the air temperature inside the TEMPSC could be low enough to cause freezing and non-freezing injuries and hypothermia in survivors within four days, if they were not protected with thermal clothing. This will be even more likely if the craft is partially flooded.

TEMPSC are generally equipped with high pressure air bottles, ventilation facilities, a route for exhaust gases from the engine, spark arrestors, and sea spray nozzles which can cover the upperworks with a film of water to protect those inside from fire. They are not normally equipped with drugs for sea sickness or loss of body fluids even though these conditions can seriously affect survival. The operation of a TEMPSC requires some navigational competence as the craft must be steered clear of the parent unit on a predetermined course. This skill is only achieved as a result of instruction and practice.

Communications during abandonment, survival, and rescue are currently provided by hand held VHF radios with duplicate sets available as back up. These secondary sets should provide back up to fitted VHF radios installed in the craft as the primary communication device. Normal TEMPSC location equipment includes a radar reflector, a distress beacon, and flashing lifebuoy light, but does not include highly reflective material, a radar transponder, or an audible signal generator. Current crafts are not fitted with a self-deploying tow-line, nor are there any other aids to transfer the survivors from the TEMPSC to rescue vessels, and stretcher cases can only be transferred in very favourable conditions. The technology is available to overcome most of these deficiencies through the supply of suitable drugs, additional radios, satellite linked emergency beacons, and appropriate towing arrangements. Suitably equipped TEMPSC of current design could therefore be expected to protect survivors in an acceptable manner if they are launched successfully.

Submerged launch systems which are still in the conceptual stage are designed to release the escape craft from below the surface of the water to avoid the problems presented by entry from above. Despite the advantages of these systems, they also introduce new hazards. Lists of 40 degrees or more could involve several design problems associated with release of the craft. The system would also have to be adaptable to a variety of water depths since drafts of offshore units vary by as much as 15 metres. Transferring people from a normal dry atmosphere to the pressurized underwater atmosphere involves complications which are similar to those which affect diving operations, particularly in deeper water. Another problem faced by designers of this system is the response time. In semisubmersibles the escape craft would probably be mounted in the pontoons. Access to these areas is only available through the columns down vertical ladders and it would take considerable time for the users to get from their normal positions in the unit to the abandonment position.

■ *INFLATABLE SURVIVAL CRAFT* Inflatable crafts are generally considered a secondary (or if helicopters are available, a tertiary) means of abandonment for MODUs and supply vessels, but a primary escape means for helicopters. They vary in size from single-person craft to those designed to accommodate up to 25 people and should be able, in extreme circumstances, to carry twice that number. Modern designs are self-inflating and contain integrated canopies.

Standard life rafts are designed to be entered from the water, and therefore do not provide a means of abandoning a unit. Inflation of life rafts in very low temperatures introduces problems, capsize during inflation is a constant threat and rafts tend to drift downwind very quickly once inflated. Life rafts must be visible to survivors in the water which would be difficult in dense fog. Considerable physical

exertion is required to board them from the water. Davit-launched rafts are strengthened and equipped with built-in slings which enable them to be lifted from a central point at the top of the canopy. These rafts can be boarded before they are lowered into the sea, but because of their lighter weight they experience an even greater risk of impacting with or drifting under the parent structure than do davit-launched TEMPSC.

Survival problems on board a life raft are more severe than those encounted in a TEMPSC. In air temperatures below 0°C it is unlikely that survivors without protective thermal clothing would be able to retain a core temperature above 35°C in a life raft for more than a few hours. If ventilation flaps were kept closed to preserve warmth, the level of CO_2 could build up to dangerous proportions. Conditions in life rafts are also very conducive to sea sickness; drugs to combat this condition are not always included in inventories. Communication equipment is generally limited to simple battery-powered VHF radios and although life rafts normally contain flares, they are not equipped with audible signal devices, radio beacons, or radar transponders. Transfer from life rafts to rescue vessels relies upon the means provided by the latter such as personnel strops and winches and is very much affected by environmental conditions. Despite these limitations life rafts provide valuable back-up systems and many of the shortcomings cited could be overcome by using existing equipment and technology.

■ *INDIVIDUAL ABANDONMENT* Individual abandonment is currently a last resort and is likely to remain so unless revolutionary advances are made in individual systems. Available survival suits with life jackets, if properly worn, can provide protection against hypothermia in all eastern Canadian waters for four hours but the survivors may drown during this time as a result of spray and waves breaking over their faces. Individual survivors are vulnerable to irrespirable gases, sea sickness, burns, and loss of body fluid. Current means of communication, location, and transfer of survivors to safety are also inadequate, and many suits on the market seriously hamper the wearer's manoeuvrability and manual dexterity. Unless the parent unit sinks or lists far enough for one part of the deck to be at sea level, individual survivors must reach the sea by relying on such aids as ropes, rungs, or chutes, all of which present considerable hazards in bad weather.

Survival suits vary significantly in terms of lifesaving capability and although extensive testing has been done on various makes of suits to determine their ability to keep a person's core temperature at survival level and to keep them afloat, these tests do not give an accurate picture of how long a person would survive in cold water while being battered by wind and waves. In general, waterproof insulated suits are most successful in maintaining core temperatures; wet suits and dry suits without insulation are not as good. A rapid decrease in core temperature occurs when water enters a "dry" suit. Some survival suits having high integral buoyancy, particularly as a result of entrapped air, present difficulties to people attempting to escape from a partly flooded helicopter cabin since they can't force themselves down in the water to pass through a submerged hatch. Other survival suits permit wearers to lie face down in the water. Survival suits and life jackets are available today which do not suffer from either of these limitations, although improvements are still desirable.

No currently available survival suit properly protects the wearer from inhaling spray or water in rough sea conditions. A prototype which may overcome this limitation is modelled after the submarine escape suits in current use with the British Royal Navy. This version is fitted with a plastic shield which totally covers the wearer's face, and has breathing holes at the top of the hood. There are also very few, if any, existing versions which incorporate adequate communication and location devices, and provide means to ensure that survivors are retained close to one another.

Helicopter suits need to be worn throughout flight, to be non-buoyant until the survivor is clear of the machine, and to be robust enough to be used several times a day. These suits will not provide as much protection from hypothermia and drowning as regular survival suits designed for use on MODUs and supply ships and which are only worn during abandonment of the unit. Survival suits for use on supply vessels should be worn not only during abandonment but also when danger threatens or when the wearer is working on the deck during bad weather. Currently available suits do not adequately fulfill this dual function.

It is important to continue to develop survival suits which provide good protection to wearers in very cold air and water, not only for individual abandonment but also to assist in survival for long periods in TEMPSC and inflatable life rafts. Secondary suits should also be developed for storage at convenient points on the rig for personnel who do not have time to don primary suits. Since individual abandonment is very much a last resort, improvements to these suits could be of use but are not considered as important as developments in dry transfer systems.

8

RESCUE

RESCUE

SEARCH AND RESCUE OPERATIONS

An Assessment of Search and Rescue for East Coast Offshore Exploration Drilling Operations
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Personnel who work offshore may have to be evacuated or rescued from mobile offshore drilling units (MODUs), supply vessels, and helicopters. A MODU evacuation can either be planned or may be initiated with limited or no warning. In each case 50 to 100 persons would have to be removed from the MODU. In a planned evacuation, a 12- to 18-hour time frame would be available for evacuation via helicopters or transfer to a supply vessel. In a limited warning evacuation, a period of one to two hours should be available for evacuation by lifeboat or life raft. Persons ending up in the water should be wearing abandonment suits, and rescue must take place within less than six hours if they are to survive. The rescue of persons from life rafts and lifeboats could, however, be safely delayed until conditions improve. In an immediate evacuation, a large number of persons could end up in the water, and some of these could be without abandonment suits. Persons in the water who are not wearing abandonment suits must be rescued within 15 to 30 minutes. As with a limited warning evacuation, the rescue of persons who managed to escape in life rafts and lifeboats could safely be delayed until conditions have improved.

The evacuation or rescue of persons from a supply vessel normally involves from 12 to 16 persons. The majority of these will most likely be in lifeboats or life rafts although it is possible that some could be in the water. Persons in the water should be wearing abandonment suits. Again, the rescue of persons from life rafts or lifeboats could safely be delayed until conditions improve.

The rescue of persons from a downed helicopter is judged to be the most difficult in terms of rescue response time. Up to 20 persons may have to be rescued and although some may, at the time of rescue, be in a life raft, all survivors will have been immersed in the water. There is also a possibility that all survivors will be in the water, but all should be wearing helicopter immersion suits. During the winter months survivors must be rescued within one hour to ensure a reasonable chance of survival, and it would seem reasonable that helicopter immersion suits providing three to four hours of protection from hypothermia should be made available.

■ *CANADIAN GOVERNMENT SAR* Canada's national Search and Rescue (SAR) system encompasses several government departments, but principally the Department of National Defence, which operates all primary SAR aircraft, and the Department of Transport, Canadian Coast Guard (CCG), which operates all primary SAR vessels. Other departments provide secondary SAR resources and have departmental SAR objectives which, although developed by an interdepartmental

working group, have not all received approval from their respective ministers. The SAR system is organized into four Search and Rescue Regions, each of which contains a Rescue Co-ordination Centre (RCC): Victoria, British Columbia; Edmonton, Alberta; Trenton, Ontario; and Halifax, Nova Scotia.

Canada's responsibilities for search and rescue are determined partly by international agreements and partly by cabinet direction. The stated objective of the national SAR program is:

> to prevent the loss of life and injury through search and rescue alerting, responding and aiding activities which use public and private resources; including where possible and directly related thereto, reasonable efforts to minimize damage to or loss of property, and by ensuring appropriate priority to aviation and marine safety measures focussed on owners and operators most commonly involved in SAR incidents.

This objective should be further developed, not only to define the areas of responsibility, but also to indicate where lifesaving is possible and where SAR activities will be limited to coordination. These responsibilities should not include the provision of salvage services. There should also be criteria against which the effectiveness of the system can be measured. On an international basis, the areas for which the national SAR system is responsible are stated to be:

> for air search and rescue . . . as provided under International Civil Aviation Organization (ICAO) agreements . . . and for marine search and rescue as provided for under International Maritime Organization (IMO) agreements, and in Canadian waters of the Great Lakes and the St. Lawrence system.

Within these areas of responsibility, the SAR system is concerned primarily with resolving distress incidents which involve civilian vessels or aircraft, but it will also assist local authorities in the resolution of humanitarian (medical evacuations) and civilian (missing person searches, small craft in inland waters) incidents when requested.

The national SAR program is administered by a lead minister for search and rescue (currently the Minister of the Department of National Defence [DND]) who is supported by the Interdepartmental Committee on Search and Rescue (ICSAR). ICSAR is comprised of representatives of the various departments concerned with the SAR program, and is led by a chairman who is currently from DND. ICSAR is designed to provide a focus so that departments involved in SAR operations can consolidate their planning, and although it is felt that this management structure should be maintained, the ICSAR Secretariat itself should be strengthened. The appointment of DND personnel to the position of chairman represents a potential conflict of interest when seeking funding for improvements to the SAR system. A similar conflict exists in the appointment of the Minister of either National Defence or Transport as lead minister for SAR. Consequently, the Chairman of ICSAR should not be appointed from a SAR line department, and neither the Minister of DND nor the Minister of Transport should be appointed the lead minister for SAR.

Each of the four Search and Rescue Regions has an overall commander (appointed by DND) who assisted by staff officers, maintains a liaison with the Regional Directors of the Coast Guard and is responsible for operating the region's Rescue Co-ordination Centre (RCC).

Funding for the national SAR program is provided entirely by the federal government. Requests for funds required to operate and maintain existing levels of SAR service, including the replacement of existing resources, are presented separately to Treasury Board for approval by each participating department as part of

its overall budget. ICSAR has no input into the formulation of these requests. This does not appear to be compatible with the existing management structure and it would seem more appropriate that the line departments submit the SAR portion of their budgets to ICSAR for presentation to Treasury Board as a single SAR budget. On the other hand, requests for funds for the improvement of the SAR system, such as for the purchase of new resources, are prepared by each line department and submitted to ICSAR where they are consolidated and submitted to the Foreign and Defence Policy Committee under the Defence Envelope. So that such funding requests as part of the Defence Envelope are not overwhelmed by defence-related items, funding requests for improvements to the SAR system should be presented to the Foreign and Defence Policy Committee as a separate SAR envelope. This action was recommended in the *Report on an Evaluation of Search and Rescue* in 1982 – the "Cross Report".

■ *EQUIPMENT AND PROCEDURES* The SAR system under the Department of National Defence has a total of nine primary aircraft stationed in the Halifax Search and Rescue Region: three Buffalo fixed-wing aircraft; three SARCUP helicopters (a recently upgraded version of the Boeing Vertol CH113/CH113A Labrador/Voyageur) stationed at Summerside, Prince Edward Island; and three SARCUP helicopters at Gander, Newfoundland. In addition, RCC Halifax has available a number of CP140 Aurora fixed-wing aircraft at Greenwood, Nova Scotia, and a number of CH124 Sea King helicopters at Shearwater, Nova Scotia, which are designated as secondary SAR resources.

The SARCUP helicopter is a twin-turbine, tandem-rotor helicopter with a normal speed of 115 knots and a radius of action, for planning purposes, of 225 nautical miles. It carries a full array of communications and navigation equipment and is fitted with a hoist. It does not, however, have auto-hover capability, which is scheduled to be installed within three to four years.

The CH124 Sea King helicopter, with a range of 170 nautical miles, carries much of the same equipment as the SARCUP helicopter. It is also fitted with auto-hover capability, making it better equipped to handle the rescue function.

Primary SAR aircraft, the SARCUP helicopters, and Buffalo fixed-wing aircraft, are on 30-minute standby during working hours (8 hours a day, 5 days a week) and a 2-hour standby at all other times. To increase the potential for rescuing persons from the water, the non-working hours standby posture for the SARCUP helicopters in Gander and Summerside should be reduced to one hour. An analysis of the time required for SARCUP helicopters to reach various locations on the Scotian Shelf and the Grand Banks indicates that they can reach the Hibernia area and most locations along the Scotian Shelf within 2 to 3 hours flying time. Locations on the southern Scotian Shelf and on the Grand Banks east and south of Hibernia may take as long as 4 hours flying time to reach. These travel times are in addition to the 30 minute and 2-hour standby times, and are inadequate to assist in the rescue of persons involved in a helicopter ditching. The analysis also indicates that the southern and northeastern Grand Banks are beyond the range of these helicopters.

There are four techniques currently being used by the SAR system to rescue or assist persons in distress: dropping a survival kit, landing a helicopter on the water or on a deck, hoisting using a net, and hoisting using a rescue technician (SARTECH). Survival kits usually consist of two inflatable life rafts joined by a line and can be dropped from helicopters or fixed-wing aircraft. This equipment, while potentially useful, only brings the survivors into a less hostile environment while awaiting rescue and requires that they be capable of helping themselves. Landing a helicopter on a deck or in the water is the quickest and most effective means of rescuing large numbers of survivors. This technique is severely limited, however, by the degree of list and motion of the deck or, in the case of an amphibious landing,

by sea state. Hoisting by net is rarely utilized by SAR personnel because the net has only a two-man capacity and is, therefore, ineffective for recovering more than two survivors. Use of the net is also restricted to those survivors capable of climbing into the net as it can only be entered from one point. Hoisting using a SARTECH makes the rescue of an incapacitated person possible even under adverse conditions since the SARTECH descends the hoist line to assist the survivor.

The Canadian Coast Guard (CCG), as a part of the national SAR program, operates a number of small rescue boats which are based at various locations along the coasts of Canada and which are used for rescues close to shore. A number of large ocean-going Coast Guard vessels, four of which patrol the East Coast, are also assigned to search and rescue duties. Of these four vessels, one is scheduled to be replaced by a vessel currently under construction. Two of the four vessels (the *Grenfell* and the *Jackman*) are former offshore supply vessels, one (the new vessel) is a supply vessel hull and the remaining one (the *Alert*) was designed and built for search and rescue duties. All four vessels have twin screws and a bow thruster; the new vessel will be equipped with joystick control while the remaining three have full bridge control of propulsion machinery. The vessels are equipped with firefighting equipment, portable pumps, first aid equipment, diving equipment, line throwing apparatus, scramble nets, and life rafts.

The *Jackman* and the *Grenfell* are equipped with crane-launched rigid rescue boats and inflatable boats, while the new vessel will have a davit launched rigid inflatable fast rescue craft (FRC). The *Alert* is equipped with two inflatable rescue boats, but will not be equipped with an FRC until its 1985-86 refit. All four vessels have facilities for helicopter winching and the *Alert* has a helipad. The *Grenfell* is equipped with a rescue basket while the other three vessels are not. The presence of bulwarks in the rescue zones of all four vessels makes it difficult for survivors to climb on board during a rescue directly from the water.

■ *POTENTIAL SAR CLIENTS* The potential users of the SAR system are the passengers and crew of aircraft and marine vessels which operate within the defined SAR areas of responsibility. This report [*see page 141*] is primarily concerned with marine related incidents, including those incidents involving the ditching of a helicopter serving the offshore industry. The potential marine client population can be defined as all those who earn their living on the sea or who use the water for recreation.

From a national viewpoint, pleasure craft constitute the single largest potential client group, particularly in the Victoria and Trenton regions where they exceed the number of licences issued to small fishing vessels. Fishermen do represent the second largest potential client group nationally and the largest in the Halifax region. Commercial vessels represent a relatively small potential client group and offshore drilling units, even smaller.

SAR statistics kept by Canada are categorized into four types of distress incidents: air, marine, humanitarian, and civil assistance. The analysis of historical data on SAR incidents in Canada revealed that the majority (74 percent) which occurred between 1975 and 1983 were categorized as marine[1] rather than air incidents[2]. Pleasure craft and fishing vessels were involved in the majority of these, with pleasure craft representing the largest number of incidents in the Victoria and Trenton regions, and fishing vessels representing the largest number in the Halifax region. Only five percent of the national marine distress incidents during this time period involved commercial vessels, with offshore drilling accounting for only a fraction of this percentage.

[1]Marine incidents are defined as those incidents where the original vehicle of transport was a surface or subsurface marine vehicle, including air cushioned vehicles when operating over water.
[2]Air incidents are defined as those incidents where the original vehicle of transport was an airborne vehicle regardless of whether the vehicle came to rest on land or on water.

■ *SAR RESOURCE DEPLOYMENT* The SAR system currently operates 42 vessels and 24 aircraft as dedicated, primary SAR resources. These resources are deployed as follows to the four Search and Rescue Regions:

	Aircraft		**Vessels**	
	Helicopters	Fixed Wing	Over 20 m	Under 20 m
Halifax	6	3	4	11
Trenton	3	1	6	6
Edmonton	0	4	–	–
Victoria	4	3	5	10

It should be noted that while Trenton lists only one fixed-wing Buffalo aircraft, it actually has several, but designates only one aircraft at a time as the SAR aircraft. A similar situation exists in Edmonton.

The deployment of SAR resources, nationally, is dominated by the following factors:

- Their proximity to previously-recorded SAR distress incidents is a major consideration in the planning of resource deployment.
- The potential user population is not a major factor in the national planning of SAR resource deployment because of the uncertainty in verifying numbers of people on board prior to an incident. On a regional basis, however, population shifts are more easily identified and, therefore, are taken into account in SAR resource planning.
- Weather and operating limits are prime considerations in the siting of SAR aircraft to ensure a high percentage of response.
- The availability of a support infrastructure for the resources and the personnel operating them is a major factor in resource deployment.
- The presence of alternate sources of SAR support is important in the planning of marine resources. For example, the presence of groups such as the Canadian Marine Rescue Auxiliary has reduced the need for SAR vessels in certain areas.

An analysis of these factors reveals that the deployment of primary air resources in the Halifax region represents a level of service which is at least equal to that provided in the Trenton region and exceeds that provided in the Victoria region. A further analysis of SAR air resources within the Halifax region reveals that the current deployment of resources (three helicopters and three fixed-wing aircraft at Summerside, Prince Edward Island and three helicopters at Gander, Newfoundland) represents the optimum locations for these resources to provide coverage for the majority of marine distress incidents. These locations do not, however, optimize the provision of service to the offshore oil industry. Relocating resources to accommodate this particular need would result, in the case of helicopters, in a downgrading of service provided to locations now covered. Therefore, the present level of SAR air resources deployed in the Halifax region should be maintained. To provide adequate SAR service to the oil industry, a dedicated standby helicopter (on 30-minute standby when helicopters are flying) is necessary for St. John's year-round, Sable Island during the winter months, and Labrador during the summer months. Because this need is peculiar to the oil industry, these air resources should be obtained from outside the government SAR system.

■ *TRAINING OF SAR PERSONNEL* In addition to their basic training, pilots of helicopters used for search and rescue must undergo a 35-day specialist course. The pilot then becomes productive as a SAR pilot and enters a phase of upgrading to

Aircraft Commander, a process which can take from one to three years. All pilots subsequently undergo continual training and regular proficiency checks are required.

Search and Rescue Technicians (SARTECHs) are selected from other Armed Forces trades and two are assigned to each aircraft. Applicants for SARTECH training attend a 35-day preselection course on survival and diving, followed by a 120-day SARTECH course which trains candidates in survival techniques, medical treatment of survivors, mountain climbing, water techniques, parachuting, and helicopter hoisting. Upon completion of training, the graduate works with a senior SARTECH for 21 months before being declared operational for both fixed-wing aircraft and helicopters. As with helicopter pilots, SARTECHs are subject to continual training with monthly requirements and proficiency checks.

Personnel on board the large Canadian Coast Guard SAR ships in the Halifax region are trained in accordance with requirements in the *Canada Shipping Act*, and the officers and some of the crew have taken the Marine Emergency Duties course (MED II) which includes some limited training in search and rescue. It is evident that MED II training, as well as basic first aid training, and training in rescue techniques used in the United Kingdom and Norway should be required of all crew members of the primary SAR vessels. Drills and shipboard exercises are conducted according to CCG standing orders and instructions. There appears to be no specific training for any of these crews in the operation of fast rescue craft, and it is imperative that CCG develop and provide such training for the appropriate number of crew members on each primary SAR vessel. Most masters and mates of these vessels have also taken the National Marine SAR course at the Transport Canada Training Institution. Indications are that CCG should, in consultation with industry, initiate the development of an appropriate course in rescue techniques.

Marine controllers in the Rescue Co-ordination Centres are Canadian Coast Guard personnel, and a CCG Watchkeeping Mate Certificate of Competency is required for this position. To qualify for this certificate, individuals must have completed MED II and have at least two years sea service although there is no assurance that they have experience with SAR equipment. Consequently, it would seem advisable to require marine controllers to have a higher standard than a Watchkeeping Mate Certificate of Competency. Air controllers in RCCs are Department of National Defence personnel who are recruited from the air crews of SAR squadrons, and who will, therefore, be pilots or navigators with experience in search and rescue operations. Since it is highly desirable to have competent personnel with experience in search and rescue operations, this practice of air controller recruitment should continue. Both air and marine controllers are sent to the National SAR course at the Transport Canada Training Institution to undergo on-the-job training before being considered fully qualified.

■ *GOVERNMENT SAR – NORTH SEA* The potential client population in the production fields in all sectors totals approximately 40,000. The maximum distance between an oil field and a designated airfield on shore is approximately 120 nautical miles, but there are numerous alternative airfields available in the countries surrounding the North Sea: Norway, Denmark, West Germany, the Netherlands, and the United Kingdom. In addition, commercial vessel and fishery patrol traffic makes SAR assistance more readily available at the site of a North Sea emergency than in the North Atlantic.

Search and rescue services in the United Kingdom are provided by Her Majesty's Coastguard, the Royal National Lifeboat Institute (RNLI) and the Armed Forces (Royal Air Force and Royal Navy). Although each agency operates independently, HM Coastguard, through an organization of six Rescue Co-ordination Centres, and volunteer watchkeeping stations, coordinates civil maritime SAR response. The Ministry of Defence, through two Maritime Headquarters/Rescue

Co-ordination Centres, coordinates Armed Forces and civil air SAR response. RNLI is a voluntary organization with 133 offshore lifeboat stations and 67 inshore lifeboat stations. The RAF provides one Nimrod long-range patrol aircraft on standby (with a second available if required), and a number of Wessex and Sea King helicopters equipped with hoists and SARTECHs. HM Coastguard provides only one air resource for SAR duties: an S-61 helicopter under contract. The total United Kingdom search and rescue services provide no additional or special equipment for response to oil industry incidents, since companies are required to provide their own rescue facilities.

Norwegian SAR services are the cooperative effort of several government agencies, volunteer organizations, and private companies, all under the coordination of the Police Force through two Rescue Co-ordination Centres, 54 Rescue Sub-centres, and 16 Air Rescue Sub-centres. The Royal Ministry of Justice and Police provides 10 Westland Sea King helicopters equipped with hoists and SARTECHs. These helicopters are manned, operated, and maintained by the Royal Norwegian Air Force. The Norwegian Society for Sea Rescue operates 29 ocean-going lifesaving vessels and eight smaller inshore vessels, all fully outfitted with rescue equipment. As in the United Kingdom, no special SAR equipment or facilities are provided for the oil industry who are deemed to be responsible for their own search and rescue needs.

■ *CANADIAN OIL INDUSTRY SAR* Oil and gas exploration off the East Coast of Canada takes place primarily on the Grand Banks and Scotian Shelf where driling takes place year round, and off the Labrador Coast and Davis Strait where drilling takes place during the summer months.

While the offshore oil industry recognizes that it has a responsibility to provide a degree of self-help in an emergency, the government SAR system is regarded as the major resource. Nevertheless, the responsibilities for responses to distress incidents involving MODUs, supply vessels, and helicopters must be clarified and agreed to by both government and industry. The industry provides an initial marine SAR response through standby vessels which are assigned to all rigs. The industry is, however, reluctant to provide helicopter rescue services with a capability fully equivalent to that provided by government SAR. The regulatory agencies require the industry, at least in Newfoundland, to provide a helicopter dedicated to search and rescue. They also require that this helicopter be equipped with a hoist and that its crew be trained in passive rescue techniques.

All operators on the Grand Banks and Scotian Shelf are required to develop joint Alert Plans which coordinate their emergency responses in the area. An alert is declared by authorized personnel when certain specified environmental conditions exist which could result in an emergency. When a Multi-Operator Alert is declared, all operators in the area are required to provide available resources according to procedures outlined in the Operators' Emergency Resources Sharing Plan. Responses to Multi-Operator Alerts are coordinated through an Operators' Management Committee consisting of one representative from each operator, with each representative relating the Committee's decisions to his respective company. This system appears to be an effective approach towards providing mutual assistance during emergencies, although the SAR system should be represented on the Operators' Management Committee when SAR resources are utilized.

The procedures taken following the declaration of an alert are outlined in each company's Alert Response Plan. Although the plans differ slightly, they include the formation of an Alert Organization and outline the responsibilities of management to bring the company to an advanced state of readiness. The Alert Organization will notify the national SAR system (an early alerting is considered vital to receiving successful SAR assistance) and the appropriate regulatory agencies that an alert has been declared. These agencies will remain on continuous

standby until the alert is terminated. Should the alert situation become more serious and develop into an emergency situation, the affected operator's Contingency Plan, required of all operators by regulation, is put into effect. Contingency Plans are intended to assist in dealing with specifically-identified emergencies by defining the responsibilities of key personnel and by outlining basic procedures to be followed. Additional procedures and manuals such as lifeboat boarding and launching procedures and well-control manuals provide more detail on certain aspects of emergencies. It appears that these Contingency Plans and their supplementary material are adequate in scope and detail. The operators on the Grand Banks and Scotian Shelf have also developed joint plans for ice management and for monitoring vessel and aircraft movements.

Standby and supply vessels report to the appropriate oil company when they arrive at or depart from a location (either offshore or on shore) and at four-hour intervals. If a vessel fails to report within 15 minutes of its scheduled time, attempts are made to contact it. When these attempts are unsuccessful, the Contingency Plan of the affected company is put into effect. These measures appear adequate for achieving a safe vessel watch, given the current level of activity.

Twice each day, supply vessel positions for each company are forwarded to Central Flight Following, a common flight watch service which has been established in St. John's and Halifax which provides a radio watch at all times when industry aircraft are flying. Aircraft report their positions along their flight paths at 15-minute intervals, and if one fails to report in within 3 minutes of the designated check-in time, attempts are made to contact it. If the aircraft is overdue by 10 minutes or if the pilots declare an emergency, Central Flight Following alerts SAR, the helicopter operator, the oil company, and the supply vessels in the area. If the aircraft is 30 minutes overdue, the emergency is confirmed with SAR and supply vessels and any available hoist-equipped industry helicopters are dispatched to the scene. Because of the transit time involved, it seems sensible that Central Flight Following dispatch supply vessels nearest the emergency at the 10-minute-overdue alert. The facilities, equipment, and procedures at Central Flight Following are, with minor exceptions, adequate to meet current needs.

■ *EQUIPMENT AND PROCEDURES* The helicopters most commonly used by the oil industry on the East Coast are the Sikorsky S-61 and the Aerospatiale Super Puma AS 332 C/L. Both helicopters are twin-turbine, single-rotor aircraft. The S-61 has a cruising speed of 115 knots and a normal Instrument Flight Rules (IFR) radius of action of about 215 nautical miles. The Super Puma has a cruising speed of 135 knots and a normal IFR radius of action of about 285 nautical miles, making it the superior helicopter among those used by government and industry SAR operations, from a logistical point of view. Communications, navigation, and other flight equipment is similar for each type of helicopter and both the S-61 and the Super Puma are equipped with an automatic flight control system. Their rescue capability, however, could be improved through the addition of an auto-hover system, direction-finding and homing equipment, and a continuous duty hoist.

The oil industry in St. John's is required to provide, on standby for rescue purposes, a helicopter equipped with a hoist. This helicopter is provided by operators on a rotational basis and can, therefore, be either a Super Puma or an S-61. This appears to be an inadequate arrangement and therefore, in each area a single helicopter should be contracted for and dedicated to this task with funding coming from the industry. The Government of Canada, however, should have the responsibility for contracting each helicopter and administering its service. This would ensure a level of training consistent with that already provided to government SAR personnel and a consistent policy on rescue techniques. In addition, industry concerns over liability and personal risk would be eliminated, and the resources could be deployed to react to changing patterns of activity. For exam-

ple, the helicopter contracted to provide services for the Sable Island area in winter could move to the Labrador Coast area in summer. This rescue helicopter may not be used for crew transport and should have permanently assigned crews of at least four persons (pilot, co-pilot, hoist operator, rescue technician). When the helicopter is on standby at the shore base in St. John's, it can be airborne in 30 minutes during daylight hours and in 1 hour during non-working hours. While this arrangement indicates a certain level of air response by industry resources, the industry must come to a consensus as to the level of responsibility it will accept for the provision of this response.

An examination of the capabilities of these helicopters reveals that Super Pumas can reach all points along the Scotian Shelf, except the southern tip, in less than two hours flying time, whereas the extreme southern tip of the Scotian Shelf is beyond the range of S-61s. Neither S-61s nor Super Pumas, as they are currently equipped, can conduct rescue missions in the extreme eastern and southern portions of the Grand Banks. Although flying times to the Hibernia area are approximately one and one-half hours, points east of Hibernia are as high as three hours flying time, a range beyond even the Super Puma. These response times are adequate for most marine incidents; however, they are inadequate for the rescue of persons following a helicopter ditching.

Industry helicopters use four techniques to rescue or assist persons in distress: dropping a survival kit; landing on the water or a deck; using an EMPRA basket hung from the cargo hook; and hoisting using a net or basket. The survival kit used in industry helicopters is similar to that used by the SAR helicopter and is subject to the same limitations, as are the deck and on-water landings by industry helicopters. The Emergency Multiple Person Rescue Apparatus (EMPRA) basket used by the industry helicopters is suspended from an external hook and is large enough to accommodate 15 to 20 persons. The EMPRA basket can be used to rescue persons from a vessel or MODU deck by simply lowering it and allowing the survivors to enter it. To rescue persons from the water, it may be trawled at the surface in an attempt to scoop up survivors. Because the EMPRA basket is suspended externally, the aircraft's speed is restricted to about 90 knots when empty and to about 50 knots when carrying survivors. These helicopters are also capable of hoisting survivors using a small, one- or two-man basket. The basket can be stored inside the helicopter while in transit and survivors can be transferred from it to the interior of the helicopter. The duty cycle of the hoist used on the S-61 is very limited, while the hoist on the Super Puma is essentially capable of continuous duty.

Government regulations require that each drilling unit must have a standby vessel in close attendance to:

- Assist in the rescue of personnel from the MODU;
- Accommodate all evacuated personnel who may be endangered due to operations on or in the immediate vicinity of the MODU;
- Assist the MODU in avoiding collisions with other vessels;
- Act as a reserve communications centre in times of emergency;
- Act as a command centre in times of emergency.

One of the prime functions of a standby vessel is to provide a site to which personnel from a MODU can be evacuated by either crane or helicopter transfer. Both methods require that the standby vessel have an open dry area, free from obstructions, where the crane or helicopter basket can be landed. The standby vessel must have the ability to maintain position while the basket is being landed, particularly in the case of a crane transfer where a position very near the rig must be maintained for a considerable period of time. Both of these techniques are lim-

ited by wind conditions which may make it difficult to land the baskets on the vessel deck.

The recovery of survivors from a lifeboat or life raft to a standby vessel is difficult and under many conditions it may be advisable not to attempt to rescue persons if there is no immediate danger to the survival craft or its occupants. There are, however, a number of avenues of assistance which the standby vessel could provide if necessary. For example, the standby vessel can assist by towing or providing a lee for the lifeboat or life raft. Survivors can be rescued using the standby vessel's crane to pick up survivors individually or in groups using a basket. Direct transfer of survivors from the craft to the standby vessel may be possible. The recovery of survivors from the water directly to the standby vessel is sometimes possible using several methods but is always very difficult as the survivor will likely be suffering from the effects of cold. A fast rescue craft (FRC) can be launched from the standby vessel to provide rapid assistance to persons in the water with greater precision and control than is possible by the standby vessel itself. Regardless of the rescue methods used, the question of survivor accommodations, medical facilities, and survivor reception areas on standby vessels should be examined and standards developed.

It is general practice in eastern Canada to use supply vessels as standby vessels. Those vessels currently in use as standby vessels should be inspected to ensure that cargo rails do not restrict access to the rescue zone and that bulwarks in the rescue zone do not result in survivors having to climb a height in excess of 2.5 metres. Where the bulwarks do create a problem, either bulwark openings or removable cargo rail sections should be installed. When these vessel characteristics and rescue equipment requirements are met, the use of supply vessels as standby vessels should be allowed to continue, even if purpose-built, dedicated rescue vessels become the norm in eastern Canada.

There are, however, some supply vessels which are inappropriate to fulfill a rescue role. Those which do not possess adequate physical characteristics to maintain proper standby position are not employed as standby vessels. When a standby vessel is used for other duties while on standby, its rescue capability is seriously compromised. Canadian regulations do not specify appropriate physical characteristics for standby vessels, the equipment they should carry, or how it should be used. It is evident that regulations or guidelines should be developed which outline the characteristics necessary for standby vessels. These requirements should include the need for rescue equipment such as a rescue basket, line throwing apparatus, safety harnesses for the crew members, and fast rescue craft with engines which can be run and warmed up while out of the water and which have launching systems capable of use in most conditions.

■ *TRAINING FOR INDUSTRY PERSONNEL* Rescue training for industry helicopter crews has been conducted by the helicopter companies in-house. Training in the use of hoists was developed after consultation with national SAR personnel, while training in the use of the EMPRA basket was developed by the companies. Training is conducted mainly in flight and includes practice of hoisting persons from the water using a one- or two-man net and using an EMPRA basket. This training is generally carried out in calm water conditions. While these helicopters and crews are primarily involved in personnel transportation, the training they receive in the use of the EMPRA baskets is useful and should be continued.

Although the original government requirement to have industry provide a standby helicopter indicated that the companies' SAR programs would be regularly reviewed and that SAR training would be provided by the Department of National Defence (DND), neither of these has occurred even though there have been several meetings on search and rescue between industry and DND. There are indications that training of crews on the dedicated standby/rescue helicopters should

be provided by SAR personnel.

Standby vessels usually have an 11- or 12-man crew of which about 50 percent will have completed the MED II course as part of the training for their marine certification. The majority of the uncertificated personnel on standby vessels have also taken MED II or a similar survival course and will, therefore, have had instruction in basic first aid. The government should, nevertheless, require all standby vessel crew members to have completed MED II training, as well as some additional formal training in the rescue techniques in use in the United Kingdom and Norway. Three members of each standby vessel crew are designated to man the fast rescue craft and they attend a course which provides adequate instruction on handling, launching, and recovery of these craft, as well as survivor recovery and care. Senior officers of supply and standby vessels also attend a two-day course called the Senior Officer-Emergency Management Forum. This course, recently introduced by the Petroleum Industry Training Service, is designed to ensure that senior vessel officers are trained to respond to emergency situations and to familiarize them with the resources available. Not all vessel officers have yet attended this course.

■ *OIL INDUSTRY SAR – NORTH SEA* The oil industry in the North Sea has developed six Sector Clubs which ignore national boundaries and which supply mutual SAR resources and aid to all operators within their sector. Helicopters are considered the primary means of evacuation, and a large number are available to assist in a SAR incident even though not all have full SAR capabilities. Standby vessels also perform SAR duties, although because of limited station-keeping and manoeuvring abilities, these vessels are primarily used to rescue persons either from a lifeboat or from the water rather than from a platform. Standby vessel crews are partly, if not all, trained in first aid and use of the FRC.

■ *GENERAL CONSIDERATIONS* A number of issues related to equipment and techniques affecting both air and marine operations require detailed examination:

- Because good visual contact by day or night is crucial to a successful rescue, consideration should be given to incorporating strobe lights on survival suits and life jackets.
- Where visual contact is inadequate or not possible, the use of an emergency position indicating radio beacon (EPIRB) would provide electronic means of locating the object of a SAR operation.
- The use of passive infra-red detection is another means of location. Forward-Looking Infra-Red (FLIR) is currently in use on some SAR helicopters in the North Sea and has been found to be very effective. This North Sea experience should be examined for possible application in Canada.
- All motorized craft, including lifeboats and life rafts should be required to have ELTs or EPIRBs, since rescue often involves survival craft in addition to individual survivors.
- Survival suits and life jackets should incorporate hand holds for rescuers.
- The recommendations made by official enquiries into search and rescue should be monitored in accordance with a formal system to ensure that appropriate actions or responses are made.

9

REGULATIONS

REGULATIONS

OFFSHORE REGULATORY SYSTEMS

Safety in the Design, Construction, and Operation of Offshore Oil and Gas Installations: A Comparative Analysis of the Regulatory Structures of Norway, Canada, United States and the United Kingdom
Dalhousie Ocean Studies Programme
Halifax, Nova Scotia
September 1984

An analysis of four different regulatory regimes which govern the design, construction, and operation of offshore installations reveals a diversity both in the structure and scope of the regulations and in enforcement practices. The regulatory spectrum varies from self-regulation by operators in the United Kingdom sector of the North Sea to the detailed regulation and enforcement policies in Norway. The offshore industry constantly tests the bounds of known technology in an effort to improve both the efficiency of its industrial operations and the safety of those employed in the industry. For regulators, the challenge is to adopt appropriate regulatory mechanisms which reflect both the innovative nature of the industry and the safety demands of the state.

■ *NORWAY* The scope of the Norwegian regulatory system is extensive compared to that of other jurisdictions. Individual regulations, however, have been designed to incorporate flexibility and to ensure that changes in technology and procedures can be adopted in individual cases reflecting the conditions specific to each operator.

The *Continental Shelf Law* provides the legal basis for control of activities on the continental shelf. It delegates authority to the King to give approval for and to regulate the exploration and exploitation of petroleum resources. Royal Decrees on the authority of that and other statutes provide the framework for issuing regulations and delegating authority for the control of these operations. Primary responsibility for the safety of offshore installations is vested in the Department of Local Government and Labour although in practice authority has been delegated to nine institutions for mobile platforms (primarily the Maritime Directorate), and to five institutions for fixed platforms (primarily the Petroleum Directorate). Five classification societies have been approved to undertake inspection and other tasks on behalf of the Maritime Directorate.

The basis of the Norwegian approach to regulating offshore safety is that the operators are responsible for ensuring that prevailing regulations are observed and that the Government's requirements are regarded as the minimum acceptable standard. An operator is required to present to the Petroleum Directorate a main plan for the exploration and/or development of a field. The plan must involve the safety policy of the operator, a safety evaluation of the conceptual design of the platform in accordance with guidelines issued by the Petroleum Directorate, and details of the operator's internal control system for ensuring its offshore activities are conducted in accordance with prevailing safety regulations.

It is a basic principle of the Norwegian system that responsibility lies with the

operator to pursue applicable safety requirements. Guidelines have been issued regarding the planning, design, construction, and operation of installations. A comprehensive statute regarding offshore oil and gas activities is under study and safety regulations are under review. Measures to coordinate the systems governing mobile and fixed platforms are already in place. In particular, the Maritime Directorate has moved to implement an internal control system for mobile platforms based on the principles and procedures already in place for fixed installations. These measures are all designed to provide a more functional regulatory system, in terms of both the number of authorities involved and the style of regulation. Most importantly, the responsibility for meeting safety standards is being placed in the hands of the licensee through the internal control system, with the authorities maintaining an overriding control position.

There are extensive regulations covering the design and construction of fixed installations and their equipment. Evaluation takes place during the planning and construction phases, although the installation is not approved until it is completed. Similiarly, the design and construction of mobile rigs are extensively regulated, particularly with respect to safety and technical standards.

Well control is exercised through specific regulations, accepted oil field practices, detailed requirements contained in Royal Decrees, and result-oriented stipulations placed upon the operator. The general framework of requirements for a safe working environment is established by statute. Regulations issued by the Maritime Directorate covering workplace safety apply to both Norwegian and foreign-registered mobile drilling units. Royal Decrees provide that the operator must ensure that persons employed on the installations have qualifications adequate to work in "a safe and reliable manner." Regulations set forth manning requirements, responsibilities of personnel, and the qualification and certification required. The Maritime Directorate has issued regulations regarding standby vessels, their physical requirements, their equipment, and the requirement that they must remain within one mile of the drilling unit.

■ *UNITED STATES* *The Outer Continental Shelf Lands Act* and the *Submerged Lands Act* provide the legal basis for control of the resources on the continental shelf adjacent to the United States. The actual regulatory regime is a mixture of four distinct approaches. The first consists of general statements of policy that provide direction to the offshore safety program. The second is equipment-specific in that it designates design criteria, construction tolerances or specific maxima or minima (for example, producing wells shall be equipped with a surface-activated downhole safety device). The third philosophy generates performance-oriented requirements describing the result that must be achieved to comply with the regulation (for example, the requirement for shutdown of pipeline pumps when abnormally high or low pressures occur). The fourth calls for the preparation and submission of equipment and operating plans by the operator, followed by government review and approval.

The implementation of these approaches is carried out through a number of instruments including statutes, regulations, executive orders, notices, circulars, permits, and standards incorporated by reference. Regulations are developed through a process prescribed by the *Administrative Procedures Act*. Proposed regulations must be published in the *Federal Register* to give the public an opportunity to comment. Executive orders are not subject to this procedure. The four agencies whose statutory authority requires them to be involved in the day-to-day regulations affecting offshore are: Department of the Interior (Bureau of Land Management and Geological Survey); Department of Transportation (Coast Guard and Materials Transportation Bureau); Environmental Protection Agency (EPA); and Department of Defense (U.S. Army Corps of Engineers).

There are many areas of potential or actual overlap in authority. Recognizing

this, the agencies have attempted to negotiate memoranda of understanding to resolve conflicts of authority, and thereby improve efficiency. These instruments are published in the *Federal Register* and are subject to public scrutiny.

There are many mechanisms employed by the regulatory agencies in fulfilling their mandates. These range from broad-brush enunciations of general policy to the imposition of extremely detailed design, equipment, and procedural requirements. In some areas, such as training and certification of personnel, the U.S. approach has favoured leaving the details up to the companies themselves. In other areas, such as the design, certification, and installation of equipment for fire prevention, well control, and workplace safety, the U.S. regulations are extremely detailed and often incorporate industry standards and guidelines. Increased demand on Coast Guard inspection personnel, increasingly complex technologies, and a current desire to minimize government involvement in the private sector have resulted in widespread use of voluntary standards and the increased involvement of classification and professional societies in the regulatory process.

An interesting development in the area of regulation in this context has been the development of what has become known as the Best Available and Safest Technology (BAST) requirement pursuant to Section 21(b) of the *Outer Continental Shelf Lands Act Amendments*. This requirement provides a general statutory mechanism whereby the Department of the Interior and the Department of Transportation ensure the adequacy of technologies and regulations dealing with offshore safety.

The responsibility for regulation of the design, construction, and survey of various drilling units is divided. In the United States the structural integrity of fixed offshore platforms is the responsibility of the Geological Survey whereas the Coast Guard has primary regulatory authority for mobile offshore drilling units. MODUs are designated as vessels and their seaworthiness (structural strength and stability) is under the jurisdiction of the Coast Guard which is empowered to carry out inspections to ensure that each U.S. registered MODU complies with the American Bureau of Shipping's *Rules for Classification of Mobile Offshore Drilling Units*. Similarly, MODUs of foreign registry are not permitted to operate in U.S. waters unless they meet the same Coast Guard requirements as U.S. registered units. Although the Coast Guard is the primary regulatory authority in this area, the Geological Survey indirectly exercises jurisdiction over the design and construction of MODUs insofar as it requires evidence of the fitness of a mobile drilling unit, including its capability to withstand oceanographical and meteorological conditions and to conduct its operations in a specific area.

Well-control regulation is the subject of a Memorandum of Understanding between the Coast Guard and the Geological Survey. This memorandum vests in the Geological Survey the regulation of "all mineral exploration and drilling, and production activities on leased or leasable land." Implementation of this agreement is by means of Outer Continental Shelf Orders which address equipment, procedures, training, and certification requirements. For instance, through *Outer Continental Shelf Lands Act* Order No. 2, the Geological Survey requires that all toolpushers, drillers, or owners' representatives take a basic course in well-control procedures and equipment every four years and a refresher course annually.

Workplace safety is not governed by one single set of regulations. Currently the Coast Guard is preparing regulations under the authority of the *Outer Continental Shelf Lands Act Amendments* to address identified workplace problems. As with construction and design, Coast Guard regulations generally apply to mobile offshore drilling units and those of the Geological Survey apply to fixed platforms. Although the Coast Guard's jurisdiction over workplace safety is derived from the *Outer Continental Shelf Lands Act*, there is a Memorandum of Understanding between the Coast Guard and the Occupational Health and Safety Administration

which provides that the U.S. Coast Guard will be responsible for ensuring that all offshore operations will be conducted in compliance with occupational safety and health regulations and are free from recognized hazards.

Numerous regulations specify the equipment and procedures that are to be employed in emergency situations on offshore installations. The Coast Guard is primarily responsible for regulating emergency and abandonment procedures and equipment on both fixed and floating platforms. There are also procedural regulations dealing with the chain of command in emergency situations. On fixed platforms the owner, operator, or agent designates the person in charge. On mobile offshore drilling units the "master or person in charge" is responsible for ensuring that all personnel on the unit and all visitors are familiar with their stations and duties during emergencies. In response to recommendations by the National Transportation Safety Board, this section is to be amended to designate the master as the person in charge.

The regulations that deal with the inspection, certification, and design of safety equipment are extremely detailed. However, with the exception of a provision that lifeboatmen be "capable of carrying out their duties" no mention is made of specific training or qualifications. Unlike the other jurisdictions under study, the U.S. regulations do not presently require the continuous presence of standby vessels. Regulations governing design, construction, operation, manning, and equipment standards for offshore supply vessels have been proposed and released for public comment.

■ *UNITED KINGDOM* Responsibility for offshore safety of oil and gas installations in the United Kingdom rests with the operator. Regulations tend to be drafted in general terms, giving the operator wide latitude in their practical application with the assistance of non-mandatory measures such as Guidance Notes. The role of certifying authorities in inspection and survey functions is significant and is supplemented by the in-house government inspection which has developed over the years. Additionally, the U.K. system emphasizes the use of external organizations, such as United Kingdom Offshore Operators Association (UKOOA) to assess and indicate the need for technical standards and regulations in order to ensure that realistic and up-to-date technologies are utilized in the offshore.

The *Continental Shelf Act* 1964, the *Mineral Workings (Offshore Installations) Act* 1971, the *Health and Safety at Work Act* 1974, and the *Oil and Gas (Enterprise) Act* 1982, provide the statutory framework for the exploration and exploitation of oil and gas resources on the continental shelf and for the safety of the personnel, the installations, and the environment. Under the authority of these Acts of Parliament, regulations are issued detailing principles of health and safety in the design, construction, and operation of offshore installations. Guidance Notes, Continental Shelf Operating Notices, Codes of Practice, Notices to Mariners and British Standards relating to issued regulations give non-mandatory advice on methods of achieving objectives to an acceptable standard of reliability. With the exception of the safety of ships and seafarers engaged in offshore oil and gas exploration and exploitation, the Department of State for Energy has full responsibility for all related safety matters. Its Petroleum Engineering Division, strengthened with the transfer of inspectors from the Health and Safety Executive, is the main governmental inspection body.

The control of industrial health and safety is based upon the principle of self-regulation. The employer has full responsibility for ensuring that appropriate health and safety specifications are adopted in the areas under his control, and for demonstrating to the authorities that the general requirements for safe operations are being met. The inspectorate's role is one of monitoring, not giving detailed instruction on fulfilling the employer's duties. To facilitate this process, legislation is kept to a minumum and regulations are written in general terms, reducing the need

for constant revisions to keep pace with technological changes. Secondary legislation and detailed technical Guidance Notes amplify the legal provisions of the system.

Under a system of self-regulation, consultation between government and industry in the drafting of regulations and guidance notes is important. Consultation is required by statute. An oil industry advisory committee has been set up but the main channel of communication with industry is the UKOOA which represents all the operators. UKOOA plays a significant role in assessing and updating Guidance Notes, preparing preliminary drafts of technical regulations for the Department of Energy and establishing non-mandatory guidelines for its members.

The Department has authorized five classification societies and one independent certification group to assess drilling units and to issue *Certificates of Fitness*. The owner of the drilling unit selects and pays the certifying authority who is responsible to the Department and applies the regulations and Guidance Notes issued by the Department. No drilling unit, mobile or fixed, can operate on the continental shelf without a *Certificate of Fitness*. The owner is responsible for sound design, proper construction, and effective maintenance of his unit.

Problems in well control require a flexible and fast response and the approach is individual treatment. The mandatory objectives are set forth in statutory instruments and advice on achieving these objectives is contained in Guidance Notes. Under the permit system the minister has wide discretion regarding the manner in which oil fields are developed and exploited. In addition to specific regulation, a wide range of instructions are issued under the regulation specifying practices to be observed to ensure the safety of the installation. Regulations make specific provisions for safety in the workplace, and for the qualifications of installation managers, helicopter landing officers, medics, and radio operators. There are also certification requirements for personnel in well control. Otherwise the onus is on the owner to provide ''competent'' personnel. A manager is required on all offshore installations, and is responsible for all matters affecting safety, health, and welfare. He is the person in charge and in an emergency has unrestricted control and authority.

Regulations are also issued dealing with emergency procedures, lifesaving appliances, and firefighting equipment which must be of an approved type. Emergency procedure manuals are required, and regulations specify that a standby vessel must be within five nautical miles of any manned installation at all times. UKOOA has issued guidelines to its members dealing with offshore safety training and well emergency drills and exercises. It has also arranged a coordinated plan with other countries involved in North Sea operations for mutual assistance in an emergency.

■ *CANADA* Although Canada has exclusive rights over the hydrocarbon resources on her continental shelf, she has not yet enacted legislation giving her jurisdiction over offshore oil rigs. The Criminal Code, for example, does not apply to foreign registered rigs nor does Canadian common law. Where Canada has not legislated nor issued regulations, only the requirements and standards of the Flag State apply. The statutory basis for regulating exploration on the continental shelf is the *Canada Oil and Gas Act* and the *Oil and Gas Production Act* under which the *Canada Oil and Gas Drilling Regulations* were issued. The responsible agency is the Canada Oil and Gas Lands Administration (COGLA). The federal parliament has jurisdiction under the constitution for ''Navigation and Shipping'', and the responsible agency is the Department of Transport. The juridical status of mobile drilling units in Canadian law is uncertain. In 1982 a Memorandum of Understanding was concluded between the Canadian Coast Guard and COGLA setting forth the terms and conditions of cooperation between the two agencies and, *inter alia*, the provision of marine services to the continental shelf and the inspection of mobile drilling

units there. By virtue of this Memorandum of Understanding the Coast Guard administers the regulatory requirements which standby and support vessels must meet. In addition, the Ship Safety Branch of the Coast Guard, is responsible for ensuring compliance with the Interim Standards that have been adapted for the design, construction, and operation of MODUs.

The primary tool for regulating the design, construction, and operation of offshore installations is the application-permit system rather than detailed regulations. Information is required on each proposed drilling unit which is then inspected and evaluated. Each applicant must obtain first Drilling Program Approval and then Authorization to Drill a Well.

The federal regulatory structure does not include a set of regulations that deal exclusively with the design and construction criteria or with certification of offshore drilling installations. The Drilling Program Approval procedures establish, however, the needed information and requirements. The unit must be capable of withstanding anticipated environmental conditions. The process of approval also includes the enumeration of specific design and equipment requirements for drilling units. The Chief Conservation Officer of COGLA will have all relevant design and construction data for evaluation and may inspect the unit and its equipment at any time.

The regulation of well control is achieved through the Drilling Program Approval which requires detailed information on the geological structure and through other regulations which outline the procedures and equipment that must be employed. Regulations also specify a number of safety-related procedures and equipment to be used to ensure workplace safety. They require the operator to ensure that trained personnel are available to operate the equipment and that safe working methods are followed in all operations. The only mention of a mandatory training requirement is the stipulation that all unit supervisors, foremen, and toolpushers must, once every three years, successfully complete an approved well-control course.

Dispersed throughout the regulations are provisions for: design criteria and equipment required for emergencies; safety drills; training; and contingency plans. Requirements also exist for suitable standby vessels as a means of evacuating personnel from drill rigs and for the rescue equipment that they should carry. Each operator is required to ensure that any operation necessary for the safety of personnel employed at a drill site or on a support craft has priority, at all times, over any other operation on that drill site or craft, and that trained personnel be ready and able to operate any item of equipment.

■ *ANALYSIS* The subject matter of regulation differs widely from jurisdiction to jurisdiction as do the mode and technique of control and the degree of detail. The legal environments also differ and, hence, there are different attitudes regarding government control. Three modes of control are evident in the four jurisdictions under examination. One mode relies on the permit system to require information and enforce compliance. The Canadian Federal Government relies heavily on this mode as does the United Kingdom, relying upon "model clauses" in general regulations and upon non-mandatory measures such as guidelines to make its wishes known. The onus is on the operator to ensure that expected and recognized safety standards are met.

A second mode is the acceptance of the assessment of another organization that an offshore drilling unit, equipment or procedure is safe. This is similiar to the way many states deal with vessels and classification societies. It is a total incorporation of standards and inspection practices of others without state regulation. It removes from the hands of the state any responsibility for establishing the details of what constitutes a safe procedure. In the United Kingdom, the United States, and Canada, this authority is delegated primarily to the classification societies. In

Norway, authority is delegated, for some purposes, to the company through the "internal control system", although detailed regulations and standards are often set by the government.

The third mode recognizes that specific areas must be regulated. A number of techinques are used. Requirements may be specific with respect to the number or the type of equipment, for example, fire extinguishers, and the performance standard of the required equipment may be set. Another technique is the incorporation of external standards or setting the criteria of inspector's approval. The approach may be to require safe performance or to specify that the performance must be by competent persons.

The technique of specific regulation is used widely in the United States and Norwegian regulatory systems. The Norwegian approach is to legislate extensively regarding the nature of the equipment, procedures, and training, and to monitor the offshore unit's compliance through spot checks and evaluation of the documents required to be submitted to the government. It is the operators' responsibility to establish an "internal control system" to ensure the safety of the drilling unit and its personnel, but the government closely monitors the companies' operations. The "internal control system" places the burden on the operator to devise a system that ensures safe operations that comply with government-established standards. The U.S. approach is less detailed than the Norwegian, but there still exist multiple equipment regulations and inspection requirements that must be met in order to obtain the necessary operating certificates. The introduction of the BAST requirement vests discretion in the agencies to determine whether equipment and procedures which may affect safety conform to specified standards.

Maximum safety is achieved through a balancing of certainty of application for the operator and legislative flexibility to permit the adoption of emerging technologies and to accommodate changing conditions. Another consideration is efficiency of the drilling operations. Undue external control will increase costs. Other considerations include administrative ease and the ability to ensure enforcement of the regulation. In selecting the mode and technique of regulation, an acceptable balance of these factors must be achieved.

The five jurisdictions addressed in the report all accept the desirability of concentrating responsibility for safety on offshore petroleum installations in as few regulatory bodies as possible. In the United Kingdom, for example, responsibility has been placed with basically one entity. In the United States two major departments have responsibility for safety in the offshore. Both departments issue regulatory instruments but duplication and confusion are minimized by inter-agency agreements in areas of overlapping jurisdiction. In Norway two directorates are involved in the coordination of offshore safety, one for fixed drilling units and one for mobile drilling units. In Canada both the federal and Newfoundland governments have established agencies which are designed to play the principal role in offshore management.

Offshore petroleum operations involve the application of the expertise of two industries, the oil industry and the shipping industry. Canada has much experience with both. Canada has little experience, however, with the two combined in the shape of the offshore oil industry. The United States also has much experience in oil and gas matters, and a long history of maritime regulation. The United Kingdom and Norway have rather more maritime experience than oil and gas experience. Nevertheless, activity outside Canada has shown that the maritime nature of offshore petroleum activities cannot be safely ignored. It can be argued that safety on offshore petroleum installations can be viewed from both the maritime and oil industry perspectives.

The federal government is attempting to concentrate responsibility for offshore management (using the phrase in its widest sense) in one agency, while util-

izing the expertise of other agencies where necessary. The Newfoundland Government has concentrated oil and gas management in one agency, and must perforce, leave the maritime component in offshore operations to a federal government agency. The task for Canadian administrators should be to determine whether this concentration is desirable, and if so, to ensure that it is not achieved at the expense of the legitimate role of other agencies.

Each of the jurisdictions examined share common problems in terms of the issues which those institutions involved in regulating offshore safety must face. Difficult questions arise, for example, in determining the need of regulation, mode of regulation, and technique of regulation. Resolving these questions requires detailed knowledge of all matters relating to offshore drilling units and technological innovations which may affect safety. Reaching decisions on these matters can be accomplished either by state institutions unilaterally or by formal or informal consultation with industry. Regulations that are created by the state without consultation with industry presuppose an enormous government knowledge of offshore operations and it is perhaps unrealistic to expect any government to be so qualified. Thus most governments in fact consult industry either formally or informally.

The major role of government in offshore safety is the creation and enforcement of regulations. Enforcement is problematic where the regulations are vague, for example, in statements of "good intentions". Enforcement is difficult where expertise is lacking to ensure compliance with detailed regulations and where no industry incentive to comply with the regulations exists. Enforcement can be accomplished through delegated power of inspection to groups like classification societies or other professional organizations. The fear of random inspection, and hence enforcement, may work when penalties are sufficiently severe.

The fact that the Canadian regulatory regime is the least developed of the jurisdictions examined is reflected in how Canada currently deals with concerns such as: the status of oil rigs, manning and training, construction and design, workplace safety, and emergency procedures and equipment.

There is an obvious need in Canada for the promulgation of legislation to ensure that national law, not foreign law, applies to all activities on board an oil rig, to the extent permissible under international law. Canada should encourage other states to accept the jurisdiction of the coastal state, thus furthering the development of the international rules. This legislation should ensure that no dichotomy in safety-related law and administrative structures exists between fixed and mobile drilling units, and production platforms. Further, the legislation should make it clear that oil rigs are not to be treated as vessels, but should have safety regulations designed specifically for them. There is a necessity as well to treat oil rigs as separate entities in regulations to avoid the problems of the dichotomy between a rig in the drilling mode and one in the non-drilling mode. Norway has taken this approach to rigs. In the United States, regulations distinguish between fixed and mobile installations. The United Kingdom has employed one set of regulations for offshore installations, whether mobile or fixed in nature. Regulations developed for ships are often not appropriate for rigs. This is particularly true in the Canadian example, since the *Canada Shipping Act* (under which shipping regulations are passed) can trace its origin to the mid-1800s, when offshore technology was virtually non-existent.

The manning and training requirements for a vessel are significantly different than those for an oil rig. In Canada, however, the only manning requirements that apply to rigs are found in the *Canada Shipping Act*. In the United Kingdom, there are no general requirements regarding training, equipment orientation, or emergency procedures. The United States is similar to Canada in its lack of regulations on manning and training. The U.S. Coast Guard has detailed certification require-

ments only for personnel performing traditional maritime activities on mobile offshore drilling units and separate regulations require that senior rig personnel complete well-control courses. The National Transportation Safety Board Report on the *Ocean Ranger* recommended that new regulations be passed on manning and training requirements for specific jobs and for emergency procedures. This recommendation is in the process of being implemented. An important strength of the Norwegian system is the detailed manning and training requirements that exist for individuals in key positions on a mobile offshore drilling unit. For some positions, course work and experience are important prerequisites. Senior personnel must have maritime certification as well as courses relating to particular drilling operations.

The Canadian federal jurisdiction is the only jurisdiction studied which does not have detailed standards and requirements regarding design and construction. In order to obtain a Drilling Program Approval an applicant must submit to the Canada Oil and Gas Lands Administration detailed information relating to the design and construction of the particular drilling unit to be employed. The International Maritime Organization (IMO) MODU Code, which Transport Canada uses as Interim Standards, provides a series of ready-made standards for rigs (although it should be remembered that the IMO Code is not comprehensive). Thus, there is an emphasis on quality of equipment but little with respect to qualifications of personnel. Both the United States and Norway have extensive, detailed regulations in these areas. In the United Kingdom the standards to be achieved and the equipment to be used are detailed in non-legally binding guidelines, which benefit from constant review through consultation with the interested parties.

The key to construction and design safety would appear to be monitoring and inspecting the work to ensure its quality. Ship classification societies, on behalf of owners, are usually responsible for undertaking the necessary inspections with the aid of government departments where their expertise is appropriate. It would be the role of the state, in consultation with experts, to determine the equipment to be tested, the frequency of inspections, and the standards to be achieved.

The United Kingdom and Norway have regulations regarding workplace safety. In both cases the legislation imposes certain duties on the oil rig operators and the employees. The United States is in the process of developing and implementing legislation on workplace safety in the offshore environment. While Canada has no significant legislation in this area, it is apparent that there is a need to establish responsibility for occupational safety.

All the examined jurisdictions have detailed regulations on emergency procedures and equipment. In all cases the state involvement in the inspection of such equipment and the assurance of the existence of an emergency plan is significant. In the United Kingdom, regulations exist regarding the type of emergency equipment that must be available on board an offshore installation. Emergency procedure manuals are to be created for every installation. There is a clearly designated chain of command established with the Offshore Installation Manager retaining overall responsibility on the installation. The U.S. regulations specify that there must be an identifiable chain of command in an emergency situation with the commander being the master unless the operator clearly designates otherwise. The operator is to prepare and have ready for inspection and use an operating manual which details activities to be undertaken to ensure and maintain the safety of an oil rig in emergency situations. Regulations on emergency equipment and procedures in Norway include training requirements and set out an onboard chain of command. The provisions for individual worker safety are extensive and detailed, extending the land-based system of safety delegates to the offshore. Provisions in the Canadian regulations regarding emergency equipment and procedures take

several forms: design criteria and required equipment; safety drills; training of personnel; and contingency plans. Contingency plans for emergencies must be readily accessible on each unit and must be submitted upon request to government authorities. There are no training requirements, although there are emergency drill requirements. Safety of rig personnel is, by law, to have the highest priority.

In striving to determine what the proper structure and goal of an offshore safety regulatory regime should be in the Canadian context, it has been useful to examine the example set by other countries but obviously that example should not be adopted thoughtlessly. What is appropriate for the Norwegian Continental Shelf may not necessarily be appropriate on the Canadian East Coast. Nor should Canada necessarily be intimidated by the superior experience of other jurisdictions. This alone does not guarantee a systematic solution to the problems posed by conducting oil and gas operations in a hostile environment. The loss of the *Ocean Ranger* has forced Canada to consider the state of its legal regime with respect to safety on offshore drilling units operating off its coasts. The questions which must now be addressed include the desirability of concentrating regulatory authority in a single agency, the proper role of regulations bearing on safety, the extent to which each individual on an offshore installation is responsible for his or her own safety, and the best way in which the proper offshore safety environment can be created and maintained.

[Editor's Note: This report and the one following were contracted in 1983 at which time a dual regulatory system existed for operations on the Grand Banks. Subsequent court decisions resulted in the federal government receiving jurisdiction over offshore drilling operations.]

(1) *An Evaluation of the Management of the Regulatory Process in Eastern Canada Offshore Drilling*
(2) *Task and Skill Analysis of Agencies Regulating East Canada Offshore Drilling*
National Petroleum & Marine Consultants Limited
St. John's, Newfoundland
June 1984

CANADIAN REGULATORY MANAGEMENT

The Canada Oil and Gas Lands Administration (COGLA) is responsible for the management of oil and gas exploration and development in the Canada lands, that is territory that under the law is not part of any province. The principal purpose for the creation of COGLA was to concentrate, within a single body, the oil and gas management functions exercised by the Department of Indian and Northern Affairs, with respect to Canada lands situated north of the line of administrative convenience defined in Schedule IV of the *Canada Oil and Gas Land Regulations* and by the Department of Energy Mines & Resources with respect to Canada lands located south of that line.

COGLA was formed in 1981, in preparation for the passage of the *Canada Oil and Gas Act*, proclaimed in March 1982 together with amendments to the *Oil and Gas Production and Conservation Act*. With a mandate to administer oil and gas activity in the Canada lands, COGLA has been made the principal point of contact between government and the petroleum industry. It negotiates exploration agreements, authorizes all activities respecting the exploration for and production of oil and gas on Canada lands, inspects exploration and production operations, and coordinates the development of related Canada Benefits' plans and the resolution of environmental concerns.

Although a single new body combining components of two departments was created, the two ministers involved retained their respective areas of responsibility north and south of the line of administrative convenience. COGLA has an unusual organizational status: it is not a program or a branch within a particular department, nor does it have the independence of a Crown corporation. It cannot be compared to most existing federal units of organization because it is an administrative body with functional responsibility to two ministers. Its authority is derived from the ministers of both parent departments and is exercised to the extent that ministerial delegation is made. Under the Memorandum of Understanding that established COGLA, both departments turned over to COGLA their respective oil and gas resource management functions for Canada lands. Each department, however, retained a substantial number of policy and operational activities with which COGLA activities must be coordinated.

COGLA is headed by an Administrator who has authority to make all ongoing operational decisions and who bears the principal responsibility for the implementation of the *Canada Oil and Gas Act*. The Administrator is also, by joint ministerial designation under the *Oil and Gas Production and Conservation Act*, the Chief Conservation Officer (the Chief). The Administrator reports to the Deputy

Ministers of both departments and receives direction from them on how he is to relate COGLA operations to relevant activities of their departments. Policy advice is provided by the COGLA Policy Review Committee, which includes senior personnel from both departments. That Committee ensures that COGLA policy decisions are consistent with the requirements of Energy Policy and Northern Policy.

COGLA is composed of six main branches. Engineering and Control is responsible for the regulation and monitoring of exploratory drilling as well as for development and production activities on Canada lands. This branch administers and enforces the *Oil and Gas Production and Conservation Act* and ensures that the operator takes all the precautions necessary for the safety of personnel, the prevention of pollution and the conservation of resources. The Land Management Branch is responsible for negotiating, issuing, and administering exploration and production rights on Canada lands. The Resource Evaluation Branch approves geophysical and geological programs and assesses the oil and gas potential of Canada lands as a basis for resource management policy. This section is also responsible for identifying seabed, surface, and subsurface geological hazards that might affect the safety of a drilling, transportation, or production system. The Environmental Protection Branch ensures that projects are environmentally safe with respect to biological and physical regimes, and acceptable to relevant coastal communities. This branch administers the southern Environmental Studies Revolving Funds (ESRF) and evaluates and approves contingency plans covering both environmental and personnel safety in the event of an emergency. The Canada Benefits' Branch is responsible for ensuring that Canada Benefits' plans submitted by operators are satisfactory to the minister. The Policy Analysis and Coordination Division coordinates roles and responsibilities between COGLA and other federal and provincial departments and analyzes, develops, interprets, and implements policy with respect to the management of oil and gas activity in the Canada lands.

COGLA maintains two regional offices on the Canadian East Coast located in Newfoundland and Nova Scotia. The regional offices are responsible for interpretation of COGLA's safety requirements to regional operators, for liaison with representatives of industry and provincial governments on safety issues, and for the monitoring and inspection of offshore operations for compliance with COGLA safety regulations. The regional offices are also responsible for granting the Authority to Drill a Well. The role of site-specific, regional monitoring, and inspection of operations is perhaps the most important function of the regional offices. In this regard, they exercise discretion on most issues, referring to Ottawa headquarters as needed. Since COGLA has the administrative responsibility for the regulation and management of the offshore petroleum resource under the terms of the Canada/Nova Scotia Offshore Agreement, the regional office there is responsible to the joint Canada/Nova Scotia Oil and Gas Board which administers that agreement as well as to the COGLA Ottawa headquarters.

Within the federal government there are a number of other programs and agencies apart from COGLA which, either by legislation or administrative arrangement, have responsibility for certain aspects of offshore petroleum activity. The Canadian Coast Guard (CCG), largely through its Ship Safety Branch, has responsibilities associated with marine aspects of drilling units and support vessels and their related safety systems. The authority to regulate these matters derives from the *Canada Shipping Act*, in the case of Canadian flag rigs and vessels; and under the terms of the CCG/COGLA Memorandum of Understanding, in the case of foreign-registered drilling units and their support craft operating under COGLA licence in the area seaward of the territorial sea of Canada. Other departments which have secondary responsibilities for safety offshore include Fisheries and Oceans, Communications, Transport, Environment, Indian and Northern Affairs, Employment and Immigration, Health and Welfare, and Labour. COGLA maintains

less formal ties with the International Maritime Organization, the Northwest European Offshore Safety Committee, the Norwegian Petroleum Directorate, the United Kingdom Department of Energy, and the United States Geological Survey.

Except in instances where they have been retained as a consultant, COGLA has no direct contact with classification societies. As far as the petroleum industry itself is concerned COGLA has no single, formal, consultative mechanism for liaison although contact is maintained through a number of informal and semi-formal means.

■ *LEGISLATION* *The Canada Oil and Gas Act* and *The Oil and Gas Production and Conservation Act* form the main legislative basis of the regulatory regime administered by COGLA. Combined, these two pieces of legislation set out the requirements for granting oil and gas exploration and production rights, for establishing a fiscal regime applicable to oil and gas activities, for providing transitional mechanisms for moving from the old to the new, and for supplying as well the framework for detailed technical and safety requirements for work and activity on the Canada lands.

There are a number of international agreements and conventions that cover marine aspects affecting the safety of ocean-going vessels and drilling units. One such accord is the *International Convention for the Safety of Life at Sea* (SOLAS) to which Canada is a signatory. Similarly, the International Maritime Organization (IMO) Code for Mobile Offshore Drilling Units specifies minimum requirements for the design, construction, and outfitting of these units. Member states such as Canada generally recognize the provisions of these conventions by promulgating regulations but may specify more stringent and detailed requirements. The MODU Interim Standards developed by the Coast Guard and COGLA used this code as a starting point although currently the Interim Standards do not have the legal force of regulations.

■ *APPLICATIONS AND PERMITS* The process of government approval to drill a well involves two stages, the Drilling Program Approval and the Authority to Drill a Well. In the first stage, an approval granted under the *Canada Oil and Gas Drilling Regulations* permits an operator to drill in a particular geographical region for a specified period of time not exceeding three years, using the drilling unit, associated support craft, techniques, and contingency plans as described in the operator's application and approved by the Chief Conservation Officer ("the Chief"). The second stage, the Authority to Drill a Well, is also granted under the *Canada Oil and Gas Drilling Regulations* and is essentially a licence to drill a particular well within an approved drilling program using the drilling procedures, blowout preventers, and the casing and evaluation programs described in the operator's application and approved by the Chief or by the relevant COGLA Regional Manager. An application for Authority to Drill a Well must include all the technical information required by the Drilling Regulations plus such other information as the Chief may require.

■ *INSPECTIONS AND MONITORING* In addition to conducting an inspection of the proposed drilling unit before the drilling program is approved, COGLA also conducts regular on-site drilling and safety inspections which are usually carried out by engineers and technologists from the regional COGLA office. COGLA also relies on the Coast Guard to control and approve the design and construction aspects of drilling units and support vessels and their related safety systems, as well as the operating, equipping, and manning of such vessels. Written reports on all inspections are prepared and circulated in the regional office and sent to the Engineering Branch in Ottawa with a copy provided to the operator. In addition the operator is required to report regularly to COGLA and other government agencies. These reports include a great deal of information: drilling data, weather information, logs or physical environment factors, summaries of significant events, litholo-

gy reports, hydrocarbon shows, and accident data involving personal injury or death. COGLA monitors these activities and ensures compliance. Deficiencies or problems encountered as a result of this inspection and monitoring activity are brought to the attention of the operator as soon as possible, often a formal statement of requirement is issued as a "directive". Whatever response is adopted, an attempt is made to maintain a continuing dialogue with the operator.

The steps taken in the enforcement process are straightforward. The initial step is for the inspector who has observed the deficiency to give notice to the operator's representative on the rig. Notice is then telexed to the operator's management. In general these steps have been sufficient to elicit a prompt and cooperative response on the part of the operator. Occasionally, when it becomes obvious that a noted deficiency is not being addressed, a warning letter setting a deadline for compliance and action is forwarded to the operator. Monetary penalties are generally provided for in the legislation but the usual enforcement mechanism is the authority to withdraw drilling permits and shut down a drilling unit.

■ *ANALYSIS* Perhaps the most important question emerging from a review of the regulatory process is the overall question of structural organization and jurisdiction. Identified as the key weakness in the offshore regulatory system of the United Kingdom by the Burgoyne Report, this controversial area has also been cited as problematic by a number of other countries. The specific safety problems created by overlapping or unclear division of responsibility are hard to predict, but it appears evident that such confusion may lead to conflicting patterns of enforcement, delays in preparing or amending legislation, and non-cooperation on the part of frustrated industry representatives.

The mere fact that this same problem crops up in discussions of regulatory effectiveness in many different countries and systems, speaks of the inherent difficulty involved in setting up a smooth and effective structure to regulate offshore exploration. The reasons for this difficulty are directly related to the special status of offshore drilling as an occupational endeavour. There are natural divisions and overlaps between marine and stationary operating guidelines; between provincial, national and international jurisdiction; and between the often conflicting but equally pressing goals of vigorous and rapid development of much-needed resources and carefully reasoned rules to protect people and property in an environment that is far more dangerous than any encountered on shore. The day-to-day problems created by overlapping or inconsistent regulatory responsibility are magnified in times of crises when the heightened risk factor and unpredictability require a speed of response and flexibility of approach that are impossible in a structure that is made up of many loosely related parts.

Offshore operations in eastern Canada have had their share of problems arising from this source. In the federal system, COGLA claims to be the window on the industry and the coordinating body for the other government departments. This is not always the case, and perhaps should not always be the case. There is evidence of confusion in the federal system regarding the allocation of responsibilities, and, even when the lead agency role of COGLA was recognized in principle, in reality it is apparent that many of the secondary agencies deal directly with industry independently of COGLA and sometimes without COGLA's knowledge. This generally occurs in areas where other government departments have traditionally exercised and continue to exercise jurisdiction, such as Coast Guard with respect to regulation of coastal and marine operations and Employment and Immigration with respect to national employment requirements.

The main source of problems may not be the particular assignment of responsibility to COGLA or elsewhere, but rather the confusion about where that responsibility lies. The same elements of confusion exist in industry, particularly among companies that are new to East Coast drilling, when it comes to determin-

ing the routines which must be followed in getting approvals and in complying with regulations in general. The present regulatory organization and structure are of recent vintage, and there seems to be little general knowledge in the industry about the organization and responsibilities of the various regulatory groups and the regulations themselves. There is no widely circulated source of updated information clearly delineating these lines of responsibility, or explaining current regulations, directives, and guidelines. This lack of systematic information is seen as an important gap in the smooth operation of the system.

A second area of concern, closely related to the first, is the danger of overlap and occasional competition between agencies which share jurisdictional control. There seems to be some feeling within industry, for example, that competition and communication break-downs exist between COGLA and Coast Guard. This situation is not, however, perceived to be a serious problem. Where there may be some difficulty, according to past experience, is liaison with respect to initial inspection and survey of drilling units. On some occasions this process has been poorly coordinated with departmental representatives acting independent of each other and with no central coordination.

A third major problem in the broad area of general organization and policy concerns the inherent conflict between the goals of industry and those of government. Regulatory agencies are sometimes seen as ruling without considering adequately the cost, efficiency, or practicality of their requirements from an industry point of view, or as ruling on the basis of political contingency rather than fundamental safety considerations.

On a local level there appears to be little justification for these statements. Although they are widely held beliefs, it is difficult to identify concrete examples where safety was actually or potentially, adversely affected by political compromise, and government regulatory agencies appear to give considerable thought to cost, efficiency, and practicality in their deliberations and decision making. A further area of policy concern among some representatives of industry is the adherence of regulatory agencies to Canadian content quotas in equipment and manpower. Although some people felt that this policy could have detrimental effects on safety standards, little evidence was found to support this claim.

A problem does exist with the degree of input by industry in the regulatory process. One symptom of this problem is the lack of industry experience within the senior ranks of COGLA and other government departments. Mitigating against the ability of these regulatory agencies to build strong, highly skilled teams are such factors as ever-changing technology which requires a constant updating of knowledge, and competition for good people arising from within industry itself. The situation in eastern Canada is exacerbated by pressures on the agencies to pursue an aggressive development strategy and to absorb the series of organizational modifications that are inevitable in a new, high-growth enterprise, while maintaining high standards of regulatory activity.

In general terms the regulatory agencies under consideration have coped well with the task of upgrading skills and general competence of their units. There is a serious need for more industry experience on regulatory staffs, particularly at senior levels. One possible suggestion for securing industry input without incurring the prohibitive costs of full-time senior personnel might be by hiring retired industry executives to provide valuable skills and knowledge on a part-time or consultant basis.

No formal mechanism is in place for industry to make their views known to regulatory agencies, or to have their concerns systematically and consistently addressed. One area where lack of input is particularly important is in the development of regulations. Regulatory groups have made it a practice to circulate proposed regulations and to solicit views from industry. The objective of these groups

is to consult with industry and to utilize their advice. Consultations, however, are informal and there is no system for industry involvement in the early stage of development of particular regulations. It is unclear to what extent industry comments are analyzed and incorporated into actual decision making.

A second, closely related concern is the lack of a formal mechanism for workers' safety committees to have discussions with regulatory authorities and to make recommendations concerning safety regulations. As the workers themselves are highly aware of occupational safety hazards, their input is seen as a significant asset.

The approval to drill procedure is an important one in the functioning of any petroleum regulatory agency. When this approval to drill is granted, it is assumed that all necessary government requirements have been met. There appears to be a problem in this area within the eastern Canadian system. There is no formal "sign off" procedure to ensure that assessments and evaluations carried out prior to approvals are all performed to the same level of effort. Without such a system, the agencies' approvals are not as clear-cut as they could be and operators have had to comply with new requirements after being given approval to drill.

Another instance of uncertainty within the local regulatory approval system is the absence of formal procedure for approval of lifesaving equipment. Occasionally, there are doubts about compliance of equipment brought into Canadian waters on foreign flag units, this doubt may exist for significant periods before a decision is made.

Regulatory agencies issue directives, guidelines, and standards and it is often unclear how mandatory they are. The understanding within the federal regulatory agencies themselves is that directives are specific to particular safety problems, and must be adhered to in order to remain in full compliance with regulations; that guidelines are compilations of directives and safety notices and that standards are non-mandatory. The main problem comes in the lack of understanding within industry of the degree of rigour of some of these requirements. On the whole, there is no definition that sets out the legal authority of each of the elements.

It is also important in any regulatory system that these directives and guidelines (as well as actual regulations) are administered fairly and consistently. There have been occasions when regulatory personnel have contacted industry personnel to inquire about actions taken or planned to be taken although the limits specified in a guideline had not yet been reached. This type of premature intervention may not have significant adverse effects on safety conditions. Nevertheless, the premature involvement of regulatory agencies potentially creates an atmosphere in which the industry feels that the agencies do not have confidence in either the limits they have set or the ability of industry to respond adequately if these limits are exceeded.

Fairness and consistency should extend to all inspection activities carried out by the regulatory agencies. One area of concern identified, related to the inspection of pressure vessels and elevating devices which appear to be the subject of overlapping and conflicting regulation. Traditionally, the inspection of these devices is carried out by trained inspectors representing provincial Labour and Manpower departments. In the case of ships, these items of equipment are also the subject of inspection by classification societies and the Canadian Coast Guard. There is often a difference in requirements and methods of inspection in a marine environment.

A general review of safety regulation activities carried out by the agencies under consideration identified some specific areas of concern. Although there are practical reasons for combining environmental safety and personnel safety under one jurisdiction, care must be taken in the review and execution of contingency plans to ensure that there are no conflicting priorities between these two domains

in the proposed sequence of events.

Although most aspects of helicopter operations are adequately regulated, there seems to be some confusion concerning helicopter landing facilities and the division of responsibility between Transport Canada and COGLA. The degree of regulatory control over drilling rigs varies depending on the country of registry. Canadian flag rigs come under tighter control than do foreign flag rigs which are monitored by the Coast Guard. Consequently, two rigs could be operating side by side and not be subject to the same scrutiny of safety features. While this situation does not mean that foreign flag rigs are less safe than Canadian ones, it does point to a fundamental flaw in the present regulatory system.

The general approach of having the Coast Guard inspect drill units was reviewed. The strength of CCG is primarily derived from its long history of regulating the marine industry, therefore treating semisubmersible drill rigs as another form of ship is natural for the CCG and, in the main, is a sensible approach. Nevertheless, there are enough significant differences between the design, construction, and operation of semis and ships to warrant very special attention. Like COGLA, CCG could benefit from incorporating more industry expertise into its work force, particularly at the inspector level.

■ *CONCLUSIONS* There is an acknowledged need for government agencies to regulate the safety of drilling operations under legislative mandate. It is of paramount importance that every operator and his operations plan be closely scrutinized by a regulatory authority to ensure that the operator has the capability to carry out the plan in a safe manner and is fully aware of any potential problems.

In general, the drilling activities themselves appear to be reasonably well regulated. The significant organization and management problems seem to arise for the non-drilling activities, that is, the operation of the drilling unit and air and marine support services. Until recently, little emphasis has been placed on these non-drilling activities.

Improvements in the overall administration of the regulatory process should result from a clarification of the responsibility of the lead agency (COGLA) for the performance of other agencies, and the provision of a clear description of exactly how the federal regulatory system works. A systematic effort should be made to educate industry on the routines involved in securing approvals and complying with regulations, and formal "sign off" systems should be established to ensure that assessments and evaluations done prior to approvals are consistent and complete. The legal authority of directives, guidelines, and standards should be defined and publicized and the methodology for designing, promulgating, reviewing, and amending regulations should be established and the information made available to relevant parties.

Improvements should also result from increased participation by industry in the regulatory process. Industry should be invited to provide input at an early stage in the development of regulations, and formal mechanisms should be established for input of workers' safety committees into safety regulatory matters.

COGLA should recognize the importance of offshore petroleum industry knowledge as a prerequisite for decision making at the senior management level, and encourage senior management personnel to augment the existing quota of expertise with input from technically knowledgeable peers and subordinates, and to increase their own exposure in this area whenever possible, particularly with regard to new petroleum-related technologies. COGLA and CCG should also place emphasis on industry-related and technical expertise when choosing and training personnel for inspectors' positions.

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